BASIC METALCASTING

James P. LaRue, Ed.D.

AMERICAN FOUNDRYMEN'S SOCIETY, INC.

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Foreword

The forming of metal shapes by casting is a fascinating activity and one that is most basic, since all metal used in manufacturing starts as a casting before it is formed into sheets, rolls, tubes, beams, wire, and other standard stock. *Basic Metalcasting* has been written to introduce the reader to metalcasting—an age-old process that is essential to industrial production and, in fact, to our way of life.

About the Author

Dr. James P. LaRue is Professor Emeritus of the Department of Industrial Technology at the University of Northern Iowa, Cedar Falls. His previous book, *Metalcasting Handbook,* is considered a standard text for those who teach metalcasting. Dr. LaRue's long-term interest in metalcasting stems from his first experience in molding and pouring as a student at Cleveland High School in St. Louis. He has been teaching metalcasting since 1947; his teaching experience includes 8 years of industrial arts at the high-school level. In addition, Dr. LaRue has been involved in industrial arts teacher education since 1956.

During his tenure at the university, Dr. LaRue held the positions of Faculty Sponsor of the Student Chapter of the American Foundrymen's Society and Key Professor of the Foundry Educational Foundation. A charter member of the Hawkeye Chapter of the American Foundrymen's Society, Dr. LaRue has served his chapter as a member of the Board of Directors, Secretary-Treasurer, Vice-Chairman, and Chairman.

Suggestions to the Teacher

This book has been written to accommodate a variety of needs that teachers might have.

The teacher who plans to teach a semester length course in metalcasting can use the entire book basically in the order in which material is presented.

A teacher with less time available can start with Chapter 5, Green Sand Molding, and continue through Chapters 6 and 7, picking up Chapters 3 and 4 when appropriate. Chapters 1, 2, 8, and 9 can be covered primarily through reading assignments.

The point is that a teacher should feel comfortable in using *Basic Metalcasting* in whatever way best fits the students' needs and the time that is available.

This book is not so technical as to be beyond the means and resources of a high-school industrial arts program. It emphasizes tools, equipment, and processes used in the school foundry. Numerous photographs are included to enable the reader to compare processes as they are carried out in the school setting and in industrial practice.

Each chapter starts with CHAPTER GOALS—a list of things the student should be able to do after studying the information in that chapter. A list of TERMS TO KNOW (defined in the Glossary) also stands at the beginning of each chapter. At the end of each chapter is a list of questions in a TEST YOUR KNOWLEDGE section.

A brief comment about several of the chapters may be helpful.

Chapter 1 may be the only chapter studied in the classroom by students in those courses in which time does not allow hands-on experiences in producing metal castings. Therefore, the material presented includes a short history, a discussion of the importance of safety, an overview of making metal castings in green sand, and a summary of career opportunities.

Chapter 2 provides enough information on foundry tooling for students at certain levels to produce patterns, matchplates, and coreboxes that incorporate features commonly found on industrial foundry tooling. Metalcasting courses that do not have time to include a unit on foundry tooling may omit this chapter or use it to develop an appreciation for the importance of foundry tooling rather than to produce such tooling. On the other hand, students who need more information than is provided in this chapter should be referred to books that are devoted entirely to the subject. Two excellent ones, both published by the American Foundrymen's Society, are

Patternmaker's Guide by Ed Hamilton,

Patternmaker's Manual

Even though the greatest tonnage of metal castings is made in green sand molds, there are several other metalcasting processes, which are discussed in Chapter 8. Some of these lend themselves to the school foundry, where important concepts can often be taught with relatively unsophisticated equipment. Teaching any or all of these processes can be used to greatly enrich traditional instruction in green sand molding. Chapter 8 shows how each process is uniquely different from green sand molding. Lists of advantages and disadvantages are provided. Pictures show how each process is carried out in industry. Suggestions for carrying out each process in a school foundry are provided.

Chapter 9 provides some answers for questions from serious metalcasting students about the future of this industry. The four main headings are Processes That Will Increase in Use; Use of New Technology; Increasing Emphasis on High-Quality Castings; and Protecting the Environment. Teachers looking to broaden their students' horizons and make the connection to industrial practice should find this chapter very useful.

Suggestions to the Student

This book employs a number of features that are designed to increase your understanding as you read:

- New terms are printed in bold type. At the beginning of each chapter there is a list of TERMS TO KNOW. All the terms on that list will be found within that chapter. Sometimes it may be worthwhile for you to look up these new terms in the Glossary before you start to read the new material.
- When a word is used in such a way that its meaning may not be completely clear unless an explanation is given, the explanation, enclosed in parentheses, follows the word immediately.
- Notes that are set off from the text contain important information that should not be overlooked.

Two features are employed to give you an idea of how well you understand what you have studied:

- At the beginning of each chapter you will find the CHAPTER GOALS—a list of things that you should be able to do after studying the information in that chapter.
- At the end of each chapter is a TEST YOUR KNOWLEDGE section, which contains questions you should be able to answer if you have a clear understanding of the material you have read.

Contents

CHAPTER 1

Introduction to Metalcasting

I. INTRODUCTION TO METALCASTING

Background • Safety • Fundamental Processes in Green Sand Molding • Career Opportunities in the Metalcasting Industry

CHAPTER GOALS

After studying this chapter, you should be able to:

1. Tell when metalcasting was first developed and why it is still one of the most important of the metalforming processes.
2. State what should be worn when working with molten metal.
3. Describe how a casting is made.
4. Name at least five different job titles of foundry personnel.

TERMS TO KNOW (see Glossary)

Crucible
Charge metal
Crucible tongs
Crucible shanks
Plain crucible tongs
Bent handle crucible tongs
Spall

Oil-tempered (waterless) foundry sand
Water-tempered foundry sand
Binder
Muller
Gyratory riddle
Corebox
Drag
Core prints

Chaplets
Cooling shed
Shakeout
Fin
Parting line
Load
Computer-aided manufacturing
Inoculant

BACKGROUND

The casting of articles with metal has a long and thrilling past. Archeological "digs" have found evidence that metalcasting began over 5000 years ago. Useful household items, weapons, statuary, and other articles cast thousands of years ago have been found in a number of places, including Mesopotamia, China, India, Egypt, Greece, and Rome.

Early metalcasters learned mostly by trial and error, and their discoveries became closely guarded secrets. Some early techniques that enabled the Chinese to cast objects of iron became a lost art, only to be rediscovered 1600 years later. Many crafts stagnated during the Middle Ages (circa A.D. 500–1500), but most, including metalcasting, were revived and began to flourish during the Renaissance (A.D. 1400–1750).

One reason explorers came to America in the seventeenth century was to find new sources of wood for making charcoal, which was used at that time to fuel European iron furnaces. The Saugus Iron Works, built near Lynn, Massachusetts, in 1642, was America's first iron foundry and its second industrial plant. The foundry produced many cast-iron products essential to life in colonial times. Metalcasting grew in importance and played a key role in producing stoves, plows, steam locomotives, and hundreds of other articles that enabled our forefathers to tame the wilderness and industrialize this great country.

Recent times have seen much change in all industries, but few changes have been as significant as those experienced in the metalcasting industry. More dramatic developments have taken place in this industry since 1950 than occurred in all of the years prior to that time. The future promises additional exciting changes.

Metal castings have more effect on our daily lives than most people realize. All metal, regardless of its final shape, starts as a casting. Almost 90 percent of all manufactured products contain one or more castings. Metalcasting continues to be one of the most basic of the manufacturing processes. The world as we know it today simply would not exist if the process of casting metal had never been discovered. The industry about which you will be learning is worthy of your time.

SAFETY

Metalcasting activities can be carried out safely in industry and in schools. The John Deere Component Works Foundry in Waterloo, Iowa, has completed 1 million hours without an accident resulting in lost time. Obviously certain precautions must be taken, particularly in the handling of molten metal, but all of life requires that we take proper precautions when crossing a street, riding a bicycle, participating in sports, riding in a car, or engaging in any of a wide variety of activities that are potentially hazardous.

In the school foundry, mold making is a very safe activity. If you avoid lifting loads beyond your capacity, there is little opportunity for you to get hurt in any way.

Much care, however, must be taken in the melting, handling, and pouring of molten metal. It is extremely important that no moisture be allowed to come in contact with a **crucible** of molten metal. This precaution, together with correct furnace operation, proper handling of the molten metal, and the avoidance of spills, will provide the type of environment in which you are at no greater risk than in any other laboratory setting.

Operating the Furnace Safely

1. Load crucible, allowing for expansion (Fig. 1-1).
2. Place extra charge metal on furnace lid (being careful not to cover the

Figure 1-1
Material should be "packed" into a cold crucible so it is loose enough to rattle if shaken.

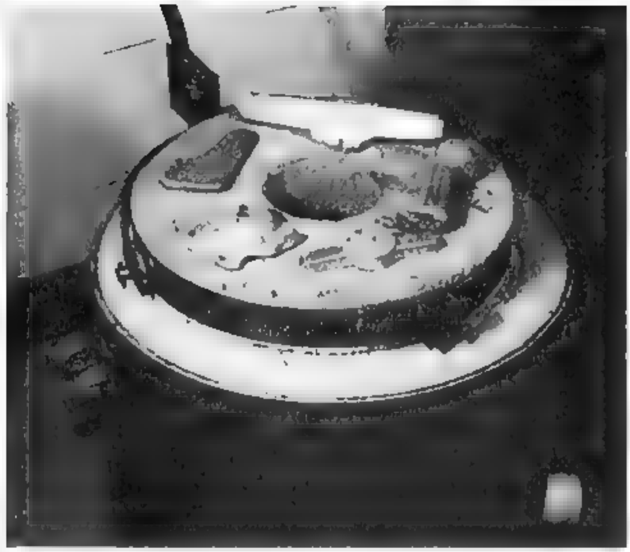


Figure 1-2
Charge material that does not fit into the crucible should be placed on the furnace lid for preheating.

exhaust port) to *drive off any moisture that might be present* and to preheat metal to reduce melting time (Fig. 1-2).

3. Place a piece of cardboard on base block.
4. Place crucible on crucible base block, centered in furnace.
5. Before lighting the furnace:
   Swing furnace lid to the side.
   Turn on the exhaust fan.
6. Light furnace according to directions provided.
7. Adjust furnace to approximately neutral atmosphere (equal amounts of gas and air—adjust so that gas flame of 4 inches comes through exhaust hole in furnace lid and then slowly reduce gas until flame gets shorter and finally disappears).
8. After metal is molten (and all **charge metal** has been added), monitor metal temperature for an appropriate furnace shut-off temperature.

Handling Molten Metal Safely

Metal melted in crucibles of the size used in school foundries is usually poured directly from the crucible into molds. Special tools are used to handle the hot crucible. **Crucible tongs** are used to remove the crucible from the furnace and place it in a **crucible shank** for pouring.

Crucible Tongs: Tongs are made to fit only *one* size of crucible. They must be designed to support the crucible in a secure manner without placing too much pressure on the side walls. This is usually accomplished with an adjustable stop, as shown in Fig. 1-3. New crucibles vary slightly in size, erode in use, and are somewhat larger when hot. Adjust the bolt to allow for these differences and to achieve a good fit on a *hot* crucible.

Smaller crucibles are usually handled with **plain crucible tongs** used by one person. However, if sufficient space exists around the furnace **bent handle crucible tongs** used by two persons are recommended for No. 10 and larger crucibles used in the school foundry (Fig. 1-4). Sharing the weight of the molten metal between two persons increases the safety factor. The handlers are more comfortable since they are farther from the heat of the crucible. In addition, bent-handle tongs are designed so that lifting the handles provide a very positive grip on the crucible.

Crucible Shanks: Crucible shanks are available with a variety of design features, but are classified as either *fixed band* (for one specific size

Figure 1-3
A properly positioned adjustable stop prohibits too much pressure on the side walls of a hot crucible.

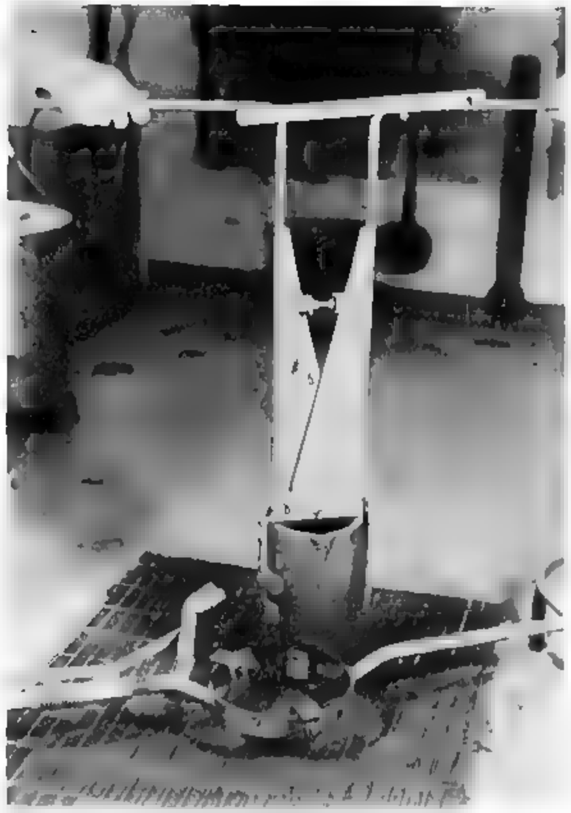


Figure 1-4
Bent-handle (two-person) crucible tongs.

crucible) or *adjustable* (with support pads that can be moved to fit two or more crucible sizes). Most crucible furnaces in school foundries accommodate a range of crucible sizes. It is recommended that adjustable crucible shanks of the same size range be purchased. Both one-person (hand shanks) and two-persons (single-end shanks) crucible shanks are available.

If one is available, use a two-person, single-end crucible shank. The weight of the crucible of molten metal is easier for two persons to lift and control, and those carrying out the pouring operation are farther from the crucible than one person using a hand shank. The shank should have such features as adjustable pad supports below the bilge of the crucible, tubular handles to reduce weight, handles offset at the band to provide better crucible balance when pouring, and some sort of locking device that will hold the crucible securely even with the shank inverted. In addition, some two-person, single-end shanks have *three safety legs* (Fig. 1-5).

The conventional single-end crucible shank is used by placing the band of the shank on two firebricks or a mound of dry sand. (A hot cru-

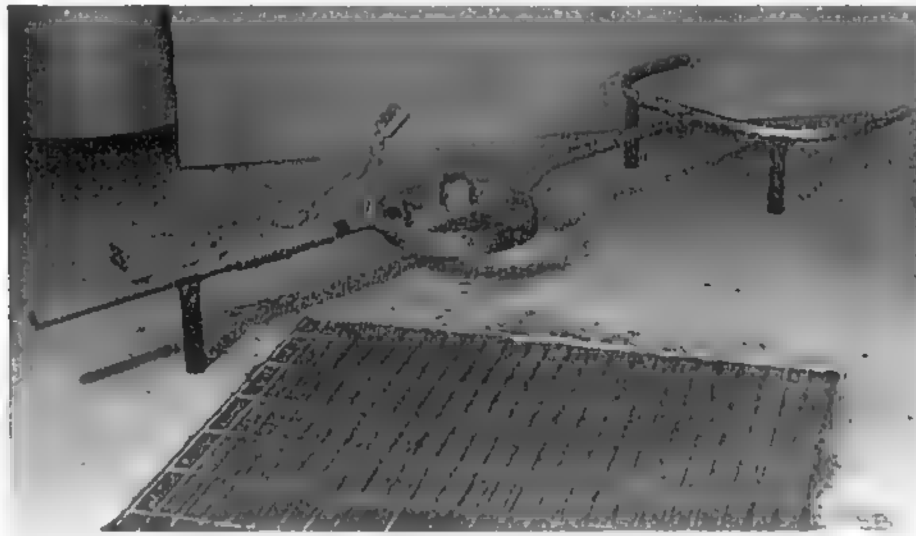


Figure 1-5
Adjustable, single-end crucible shank used by *two* persons. Notice the three safety legs, which provide stable support for the shank.

cible must not be placed on concrete because it will **spall** the concrete or at least leave a scorch mark.) The crucible is then placed on the firebrick or sand in the center of the band, after which the shank can be raised to capture the crucible. The spring-loaded safety finger is then positioned on the top edge of the crucible, and pouring proceeds. When the crucible is set on the firebrick or sand in the center of the band, it is free-standing until the shank is raised to capture the crucible. In addition, the shank is more or less balanced on the firebrick or sand. Anyone tripping on either shank handle could tip over a full crucible and cause a spill of molten metal—a serious hazard.

A two-person, single-end crucible shank *with safety legs* eliminates all of these problems. Such a shank will:

- Provide stable support for the shank (it does not have to be balanced on its band on firebrick or a mound of sand).
- Greatly reduce the possibility of tipping over a crucible of molten metal should someone trip over the shank handles.
- Hold the band off the floor (firebrick or sand) so the crucible can be released from the tongs directly into the shank and is never left in a hazardous freestanding position.
- Eliminate the need for firebrick or a mound of dry sand, a stumbling hazard, in the pouring area.

It is recommended that school foundries with conventional two-person, single-end crucible shanks modify them with the addition of safety legs.

Minimum Safety Apparel for Working in the Foundry

If you have a relative who works in industry, you may know that there are certain protective devices that employees must wear. Safety glasses and hearing protection devices are common. Certain kinds of foot protection and special clothing may also be required.

Wearing appropriate safety apparel when working in a school foundry is also most important. Be sure to:

- Wear proper eye protection—safety glasses with side shields that meet OSHA requirements are recommended.
- Wear appropriate footwear—regular, leather work shoes provide much more protection from falling objects and spilled molten metal than sneakers or jogging shoes.
- Remove hazardous jewelry—rings and watches should be removed as well as any bracelets or necklaces.

Special Safety Apparel for Melting and Pouring

Never take chances when working with molten metal. The Boy Scout motto, "Be Prepared," is worth following—wear some special protective equipment in addition to safety glasses and appropriate footwear. Wear the following equipment when working with molten metal.

Melters and Pourers Face Shield: Do *not* use an ordinary plastic face shield. The proper type of face shield has a 24-mesh steel screen visor that covers the entire face and neck area. Some heavy-duty face shields include a plastic visor *under* the steel screen visor.

Leggings: Clip-on leggings of flame-resistant materials are more convenient to use than the type that requires snaps. The pants legs should be pulled up and "cuffed" over the top of the leggings to ensure that metal cannot splash *between* the protective leggings and the pants (Fig. 1-6).

Gloves or Mittens: Hand protection made of heat-resistant material that feels comfortable and provides confidence in the ability to grip securely should be worn. If gloves are not tight at the wrist (gauntlets), tuck the cuffs inside the sleeves of a protective coat or fasten them tightly around the wrists with rubber bands (Fig. 1-7).

Figure 1-6
It is important to "cuff" pants leg over the top of the leggings.

Figure 1-7
Heat-resistant terry cloth gloves. Gauntlet cuffs should be tucked inside the sleeves of a protective coat or fastened tightly at the wrists.

Other Protective Garments: Aprons and sleeves such as those used in electric welding or a protective coat of heat-resistant material will provide protection from the heat as molten metals are handled.

FUNDAMENTAL PROCESSES IN GREEN SAND MOLDING

Green sand molding is only one of many ways to make useful metal castings, but it is a very important process. More tons of metal castings are made in green sand molds than are made in all the other metalcasting processes combined. The sand used in this process is not green. It is whitish until additives or repeated use cause it to appear brownish or black. "Green," in this case, means moist. To make a green sand mold, you must use sand with the proper amount of moisture.

Sand Conditioning

You must first determine what type of sand you have. **Oil-tempered sand** will have a sticky feel that is not present with **water-tempered sand.**

Waterless Bonded (Oil-tempered) Sand: Oil-tempered sand is often used without conditioning between use. However, sooner or later it will need to be revitalized with small additions of **binder,** oil, and catalyst and mulled until satisfactory green strength is achieved.

Clay Bonded (Water-tempered) Sand: Water-tempered sand needs to be tempered for each use. Sufficient water is added and mixed thoroughly until all the sand is uniformly moist. Excessive moisture, which results in substantial amounts of sand sticking to your hand, should be carefully avoided. *Metal will not lie quietly on sand that is too wet, and poor castings will result.* The easiest way to mix the water into the sand is with a **muller.** However, the sand can be cut, turned, and hit with the back of a shovel as it is sprinkled with water until the batch is completely blended. Putting such sand through a **gyratory riddle** will further improve its condition by fluffing and aerating.

Hand-Squeeze Test: A squeezed handful of properly conditioned molding sand (water- or oil-tempered) will retain an imprint of the fingers, support itself when held by one end, and break with sharp corners. Not much sand will stick to the hand (Fig. 1-8).

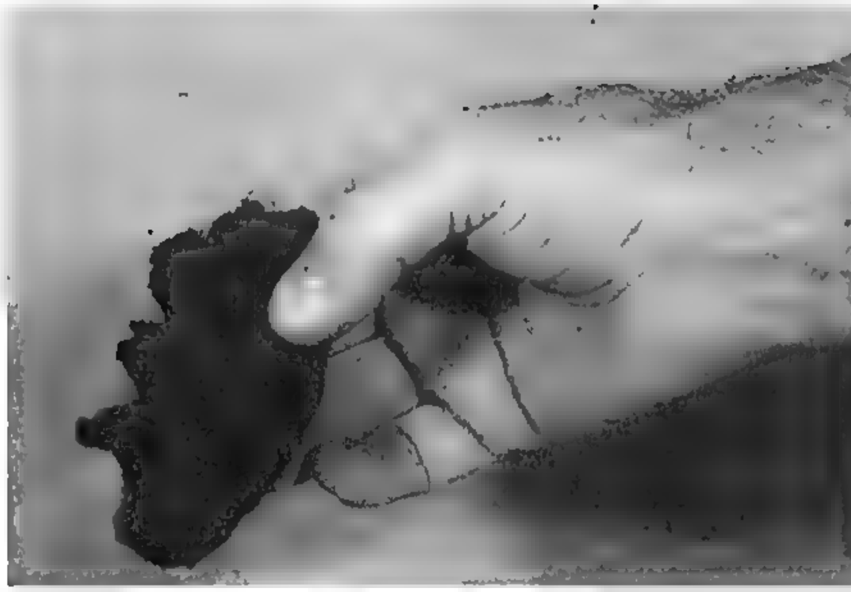


Figure 1-8
A squeezed handful of properly conditioned foundry sand should retain finger imprints and support itself when held by one end.

Mold Making

Molds are made in flasks (Fig. 1-9). The sand is packed tightly around a pattern. The pattern is removed leaving a cavity in the sand the exact

Figure 1-9
Lightweight aluminum flasks are easier for students to handle.

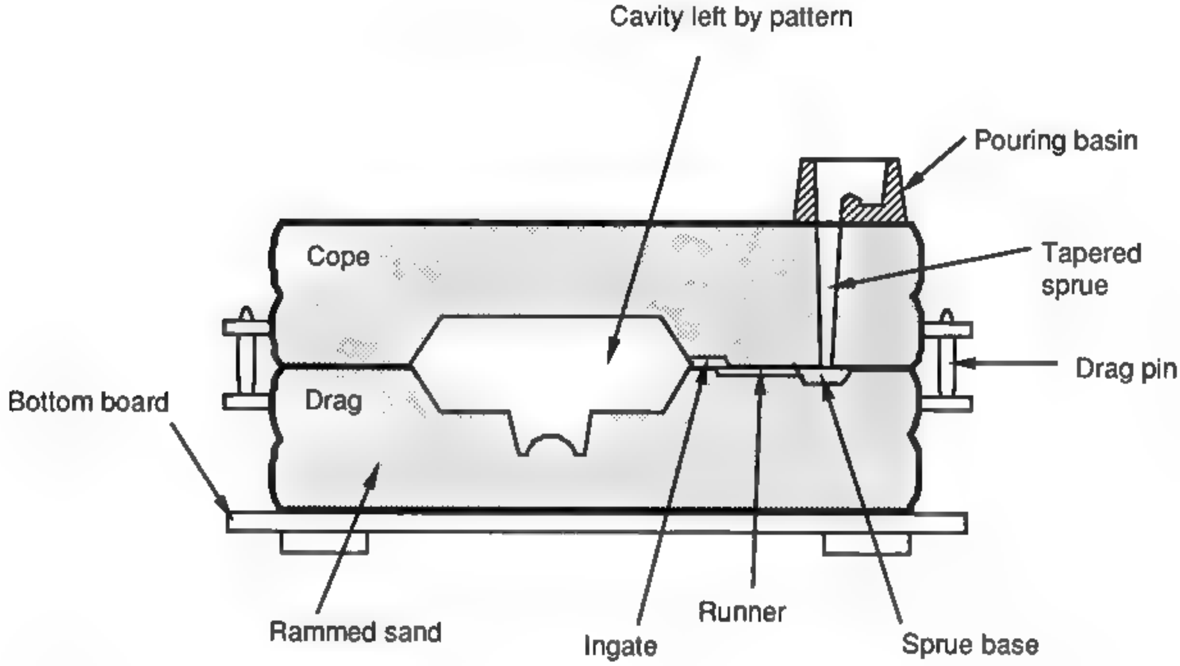


Figure 1-10
Cutaway view of a completed mold.

shape of the pattern. A sprue (hole) must be made and runners and gates (channels) cut through the sand connecting the bottom of the sprue with the cavity. All the openings in the mold are filled with molten metal when it is poured (Fig. 1-10).

Coremaking and Setting

Just as the mold cavity provides the external shape of the casting, any holes or other internal shapes in the casting are produced with cores. These cores are made of sand by one of many processes. In all instances, a specially mixed or coated sand is placed in a **corebox.** There, it takes the shape of the cavity in the box, becomes hard, and is removed. When a mold requires one or more cores, they are made ahead of time so they will be ready when needed. After the mold is made, the flask opened, and the pattern removed, cores are set in the **drag** just before the mold is closed. Cores are supported in the mold in **core prints** (Fig. 1-11). Specially designed metal supports called **chaplets** are also used when needed (Fig. 1-12). When the metal is poured, it will fill the mold cavity except for where sand cores are present. The shape of the solidified casting results from the shapes of the mold and the sand cores.

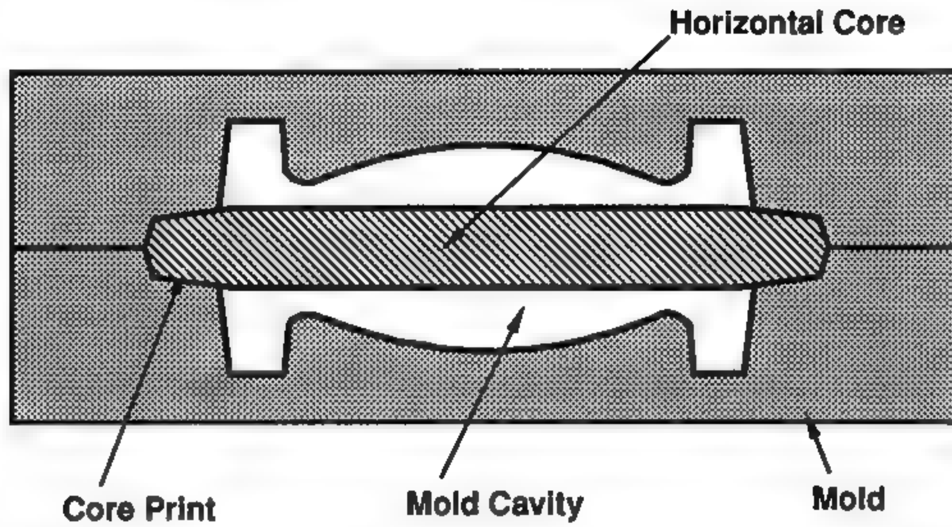


Figure 1-11
Cores are set into core prints—specially formed areas that are produced when the mold is made.

Figure 1-12
Chaplets, which come in various sizes, are sometimes needed to help support sand cores in a mold.

Melting and Pouring

In industry, a variety of furnaces are used to melt many different kinds of metal. Each of the following furnaces has certain features that would recommend it for a specific melting application:

- Cupola
- Reverberatory
- Electric arc
- Induction
- Crucible

The stationary, lift-out, natural, or LP-gas–fired crucible furnace is the one most commonly used in school foundries (Fig. 1-13). Nonferrous metal, especially aluminum, is widely used. Such furnaces will melt aluminum in 12 to 15 minutes; brass or bronze takes one and a half times as long. Avoid heating aluminum above 1450F. Higher temperatures will damage the metal. Melt nearly full crucibles of metal. When the metal is ready for pouring:

- Handle the crucible with tongs and a shank properly sized to the crucible.
- Be sure that the two halves of the flask are clamped together or that sufficient weight has been placed on the top of the flask to keep it closed.
- Pour rapidly, to keep the sprue hole full.
- Pour extra metal into ingot molds.

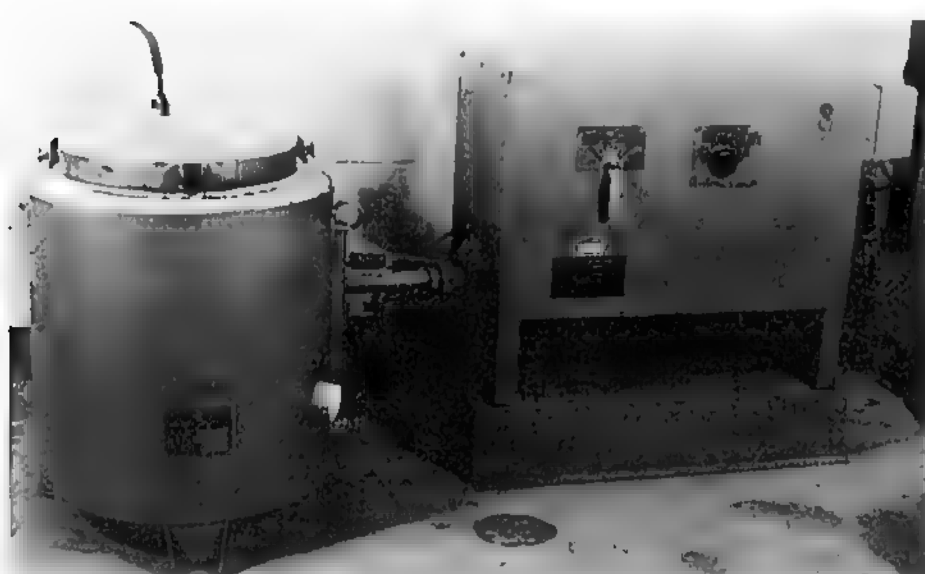


Figure 1-13
Gas-fired crucible furnace appropriate for the school foundry. This furnace has an ultraviolet safety system (highly recommended) and push-button operation.

Shakeout

In industry, large castings often remain in the mold for some time. Large flasks might take an hour or more to move through a **cooling shed.** From there they proceed to **shakeout,** where castings are removed (Fig. 1-14). In the school foundry, small castings can usually be shaken out in a few minutes. However, avoid ruining a casting that otherwise would have been good by opening a mold too soon. A useful rule of thumb is: Wait *twice* the length of time required for the top of the sprue to solidify after pouring.

Cleaning and Finishing

Industrial castings often require additional cooling after shakeout. Then, gating systems are broken off or are separated by sawing, abrasive cutting, or flame cutting. The castings are then cleaned by tumbling, shot blasting, or other suitable methods. From there they go to the "chip and grind" department, where **fins, parting lines,** and slight defects are re-

Figure 1-14
Bridge crane operator (*upper right*) raises flask from shakeout table where vigorous vibration loosens the sand, causing it and the casting to drop out of the flask.

moved. In the school foundry, gating systems are usually removed with a hand hacksaw or a metal bandsaw. Fins and parting lines are removed with a hand file or belt grinder. *Don't use a regular, general-purpose grinding wheel for aluminum or brass or you will* **load** *the wheel.* Sandblasting equipment or a wire-wheel power buffer can be used to provide a finished appearance on nonferrous castings.

CAREER OPPORTUNITIES IN THE METALCASTING INDUSTRY

You may be interested in working in a foundry. The metalcasting industry provides a wide variety of job opportunities. In recent years, although the total number of foundries in the United States has decreased, the total number of employees has stayed about the same, and the total tons of castings shipped has increased. These facts show the stability of this most basic industry. They also testify to the progressiveness of the industry, which is continually improving production through mechanization.

The modern foundry has few jobs involving hard physical labor. There are jobs for persons with few skills as well as for those with very advanced education of a technical nature. Some of the opportunities are described below.

Laborer

All foundries require a substantial number of laborers. Such employees drive forklift trucks or move materials by other means. They are responsible for keeping the foundry clean, or are assigned to a variety of other supportive tasks. These jobs are rated as unskilled, which means that little or no specialized training is necessary for the worker to be productive. The demand for unskilled laborers is dwindling as more manual operations are replaced by mechanization.

Patternmaker

Patterns are necessary to produce the mold that shapes the metalcasting. The pattern is a key part of the process. So, too, is the person who makes the pattern. A patternmaker must be skillful in working to close tolerances with hand tools as well as with a variety of woodworking and metalworking machines. Wood, metal, plaster, and plastics must be familiar materials. The ability to visualize the three-dimensional object to be produced from the blueprint is extremely important. If you possess these attributes and thrive on variety, you may want to find out more about patternmaking. Patternmakers normally learn their trade by completing

apprenticeships and becoming journeymen. Patternmaking is one of the highest paid and most important of all the trades. In the future, patternmakers will use **computer-aided manufacturing** (CAM) work stations and intersecting laser beams to produce patterns.

Molders

A molder uses pattern equipment to produce a mold, generally of green sand. (It should be remembered that green sand molding is but one of a number of ways to produce metal castings.) The molder also may be responsible for setting cores in the mold. As described earlier, molten metal is poured into the resulting cavity to produce a casting. The simplest form of green sand molding is *bench* molding, a fairly slow process that requires little in the way of sophisticated equipment. It is used a great deal in school foundries but very little in industry. Many different kinds of *machine* molding are more common to industrial metalcasting. The skills required by a molder are usually learned in a vocational foundry class or on the job. Physical strength and stamina have traditionally been important, but these attributes will be of lesser concern in the future as more molding processes are carried out by the push-button operation of highly mechanical and automated machines.

In smaller plants molding can involve substantial variety, which makes the job more exciting. Long production runs in larger plants might make for substantial monotony. If the responsibilities of this important member of the metalcasting team appeal to you, you may want to learn more about the occupation of molder.

Technician

A wide variety of tasks in a modern foundry must be carried out by technicians, who normally require some technical training beyond high school. They need to be practical minded and enjoy the challenges of investigating and solving problems. An inquisitive nature, which seeks to know why something operates as it does, is an important attribute. A brief description of a number of technicians important to the foundry industry is provided below.

Sand Technician: The sand technician is responsible for maintaining the sand system within specifications. He or she continually tests for certain properties of the blended core and molding sands and adjusts the proportions of the various additives to maintain the desired quality.

Melt Technician: The melt technician ensures that the poured metal meets all proper specifications. He or she closely monitors the quality and amounts of various metals and alloying elements used in the charge. Melt

technicians are also responsible for monitoring furnace conditions, metal temperatures, and the addition of necessary **inoculants** at the right time.

Laboratory Technician: The laboratory technician has usually specialized in a particular area of metallurgy or chemistry. He or she works with scientists and/or engineers in conducting both mechanical and nondestructive tests and in recording data. Such data are of critical importance in verifying that all operations of the metalcasting process are within specifications. Test data are also important in the evaluation of new ideas that might improve existing procedures.

Safety Technician: Safety technicians are responsible for maintaining a safe environment and working conditions. Careful recordkeeping and analysis of accidents in order to identify and eliminate hazardous situations in the workplace are important responsibilities. The safety technician is required to administer programs to make all workers more safety conscious. Some safety technicians are given responsibilities over very specific aspects of safety. For example, an environment technician takes air samples to determine the levels of respirable dust and suggests means of protecting employees from exposure to excessive levels.

Maintenance Technician: Maintenance technicians are responsible for establishing work order completion times (estimations) for various types of maintenance work, including preventive maintenance (PM). They also plan and schedule such work. It may be necessary to gain some experience as a skilled tradesperson before becoming qualified as a maintenance technician.

Engineer

The metalcasting industry requires several types of engineers. Some typical job titles are discussed below. Each title reflects that position's main responsibility. In addition, an engineer must be knowledgeable about the management of the foundry. Preparation for such a position usually involves completing a 4-year college program with a major in engineering or industrial technology. In some cases, however, engineering positions are assumed by those who have applied themselves diligently at each of the jobs they have had within the industry and have improved their technical knowledge by studying in night school, at the Cast Metals Institute, or on their own. Engineers are considered professionals rather than laborers or tradespeople. They are normally paid salaries rather than an hourly wage.

Process Control Engineer: The process control engineer is responsible for continuously monitoring and improving all the many processes

involved in making metal castings. The first concern of such an engineer is to ensure that processes and procedures currently being used are being carried out in a controlled manner. "Bugs" in a process must be eliminated. Procedures must be clear so that different persons following a procedure will achieve similar results. When all is operating smoothly, the process control engineer will analyze the process for ways to increase production, such as increasing mechanization, improving the conveyer system, or using a different core process.

Quality Control Engineer: Engineers responsible for controlling the quality of castings have an essential role in producing castings that will satisfy customers. The quality control engineer's main job is setting up visual, dimensional, and metallurgical inspection procedures to check the quality of cast metal parts. The selection and supervision of appropriate tests and the determination of what percentage of castings should be inspected are important aspects of the job. Analyzing scrap castings to determine why they are deficient and working with the process control, metallurgical, or chemical engineer to eliminate defects are also the quality control engineer's responsibilities.

Metallurgical Engineer: A metallurgical engineer must understand the fundamentals of any metalcasting processes being carried out at the foundry. In addition, he or she must be highly knowledgeable about metals and alloys. The melting points and other physical properties—such as hardness, strength, and grain structure—of metals and alloys are important to a metallurgical engineer. He or she evaluates metal castings and specifies procedures for melting, alloying, and pouring molten metal to obtain castings that are within the required specifications (Fig. 1-15).

Chemical Engineer: The job of the chemical engineer is one of the most dynamic positions in the metalcasting industry. Many of the recent developments in binder systems for molding and coremaking are the result of chemical research. New chemical coatings are continually being developed and tested in an effort to improve the soundness, dimensional accuracy, and surface finish of castings. The chemical reactions generated by such materials as they come in contact with molten metal is an area of major interest to the chemical engineer.

Technical Sales Representative

Have you ever thought you might like to be a salesperson? Many of these are needed in the metalcasting industry, in which they play a very important role. Some sell materials or equipment needed to produce castings. Melting furnaces, refractories, and equipment of many kinds, as well as metals, sand, clays and other additives, oils, and chemicals, need

Figure 1-15
A metallurgical engineer conducting a nondestructive test on a casting.

to be presented and sold to the industry by knowledgeable salespersons. These persons must be aware of the latest developments in metalcasting technology. They also must know something of the specific needs of the customer.

A second type of salesperson important to the metalcasting industry is one who sells castings. Such persons must have a good technical background. They must understand the design and proper application of castings. They must know about the properties of various alloys and how to select a specific alloy for a certain application. They must know the capabilities, limitations, and production schedules of their foundries. They should be able to work with both customer's and producer's engineers in achieving improved casting design and material specifications. In addition to the attributes described above, casting salespersons should be self-

starters, enjoy working with people, and have a strong personal desire to succeed.

Executive

On the top rung of the career ladder in the metalcasting industry is the executive, who may have the title of general manager, plant manager, or works manager. Usually this is a college-trained person who has worked up from a technical position. Metalcasting executives must have a good understanding of all aspects of the industry and an ability to manage people. The number of executive positions is limited. The responsibilities are great but the rewards, in terms of salary and personal satisfaction, can be substantial.

Summary of Career Opportunities

It is clear that a broad spectrum of talents and abilities are required in the metalcasting industry. So, if you are interested in pursuing a career in the metalcasting industry, there is likely to be a place for you.

TEST YOUR KNOWLEDGE

Write your answers on a separate sheet of paper. Do not write in this book.

1. One reason explorers came to this country was to find new sources of wood for making __________.
2. What safety precaution should be observed when making molds?
3. What is the most important reason for preheating metal before adding it to molten metal in a crucible?
4. Before lighting a crucible furnace, the exhaust fan should be turned on and the furnace lid __________.
5. Name three pieces of safety apparel that should be worn when handling molten metal.
6. Describe a common method of testing molding sand to see if it has been properly conditioned.
7. Green sand molds are produced by ramming sand around a pattern in a __________.
8. Holes in castings are produced with the use of __________ __________.
9. Sand cores are supported in molds in core prints or with __________.

10. The furnace most commonly used in school foundries is called a ________ furnace.

11. The most commonly used metal in school foundries is ________.

12. Removing castings from green sand molds is called ________.

13. Match the following job title to the responsibility:

_____ Laborer	a. Responsible for quality of castings
_____ Executive	b. Produces molds
_____ Patternmaker	c. Manages the foundry
_____ Sand technician	d. Promotes safety consciousness of workers
_____ Technical sales representative	e. Sweeps floors
_____ Quality control engineer	f. Monitors sand system
_____ Metallurgical engineer	g. Produces patterns, core boxes, and other foundry tooling
_____ Safety technician	h. Sells materials and equipment to foundries
_____ Molder	i. Specifies procedures for melting, alloying, and pouring molten metal

CHAPTER 2

Foundry Tooling: Patterns, Matchplates, and Coreboxes

Draft • Patterns Larger than Castings • Pattern Shop Materials • Wood Patterns • Matchplates • Coreboxes

CHAPTER GOALS

After studying this chapter you should be able to:

1. Discuss the relationship of the patternmaker to the production of metal castings and indicate the level of skill required in this trade.
2. Describe what is meant by *draft*.
3. Explain why a pattern might have to be made with a double shrink allowance.
4. Name at least two fillet materials and describe how each is installed.
5. Describe how hard plasters are weighed, mixed, and poured, and indicate what needs to be done *after* pouring and *before* the plaster has set.
6. Explain how a matchplate might be cast in green sand with a loose pattern and oversize flask.
7. Describe what is produced in a corebox and explain how it is used to achieve certain features in a metal casting.

TERMS TO KNOW (see Glossary)

Draft
Shrink
Shrink rule
Double shrink
Average moisture content
Paper/glue joint
Loose pieces

Drawback
Pickout
Loose pattern
Plain plate
Matchplate
Composite plate

Cope plate
Drag plate
Core drier
Core blower
Core stick
Core plug

Foundry tooling is a term that refers to any device that has something to do with producing the shape of the mold cavity or the cores used in that cavity. Such tooling is *essential* in the production of metal castings. Most foundry tooling is produced in pattern shops by patternmakers.

The patternmaker must be very skillful in working to close tolerances in wood, metal, plastics, and plasters. In the past, wood was the primary material used to construct foundry tooling. Modern foundry processes require tooling that is more durable and more resistant to abrasion than wood tooling. Therefore, much foundry tooling used in today's metalcasting facilities is made of metal or plastic. Even so, the original master patterns used to produce the production tooling of metal or plastic are made of wood. Plaster or plastics may be used by the patternmaker to achieve certain complex contours or shapes. Even though other materials are used, wood is still a material of considerable importance in the production of foundry tooling.

Two critical aspects of patterns, matchplates, and coreboxes are 1) they must have draft; and, 2) they must be properly oversize, to allow for the shrinkage of the metal that will be used to make the casting and for any machining that must be done.

DRAFT

Patterns must have **draft.** This means that vertical edges must slant inward or be tapered. Draft allows the pattern to be drawn from the mold without damaging the cavity (Fig. 2-1).

A common draft angle is 2 degrees. However, a deep shape, such as a truncated cone, could have less draft. More draft should be used for hanging green sand cores that are shallow and/or fragile. (A hanging green sand core is a core of molding sand that extends from the top of the mold, below the parting line, into the drag portion of the mold. It is produced by the pattern when the mold is made.)

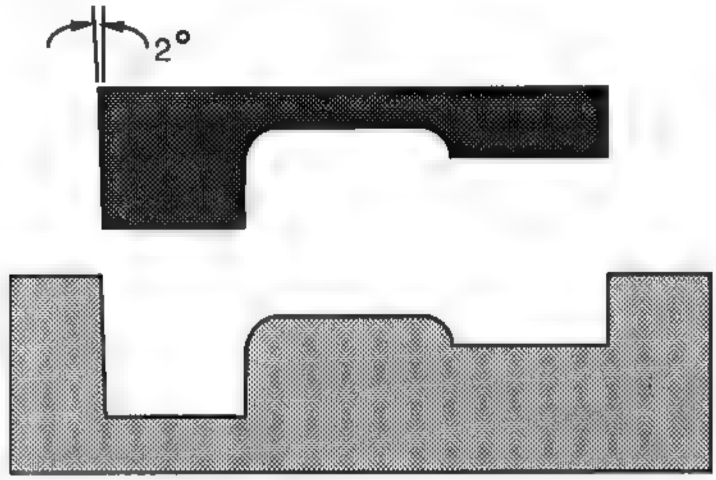


Figure 2-1
Draft on vertical edges enables the pattern to be removed without damaging the mold activity.

PATTERNS LARGER THAN CASTINGS

Shrinkage Allowance

Almost all metals **shrink** during solidification and cooling. (Antimony hypereutectic cast iron, and bismuth are exceptions; they *expand* on solidification.) Such shrinkage must be anticipated and accommodated if useful castings of correct size are to be produced. The problems of shrinkage that occur *prior to* and *during* solidification must be solved by the mold maker. The problem of shrinkage that occurs *after* the casting has solidified and while it cools to room temperature is solved by the patternmaker, who makes the pattern slightly *oversize*—larger than the desired casting. This task is simplified by selecting a **shrink rule** matched to the shrinkage of the metal to be poured (Fig. 2-2). Shrink rules are available in approximately 12-inch or 24-inch lengths. Metric shrink rules are also available. Metals shrink at different rates, as shown below:

- Aluminum alloys shrink 5⁄32 inch per foot.
- Brass shrinks 3⁄16 inch per foot.
- Cast iron shrinks 1⁄8 inch per foot.
- Steel shrinks 1⁄4 inch per foot.

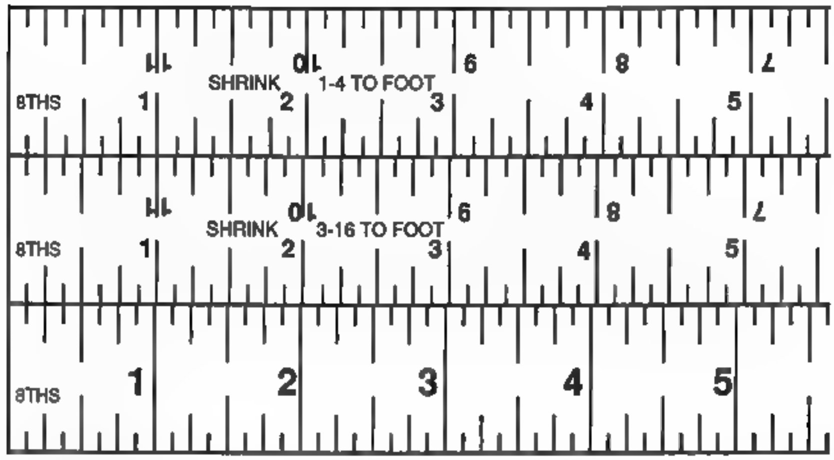


Figure 2-2
A shrink rule (*top*) looks very much like an ordinary rule (*bottom*), but each "foot" of such a rule is larger by the amount that 12 inches of the specific metal shrinks as it cools from its solidification point to room temperature. The top rule (shrink $\frac{1}{4}$-inch per foot) would make a pattern sufficiently oversize for a steel casting. The center rule would be used to make a pattern for producing brass castings.

Double Shrink

The metal patterns used in industrial molding processes are produced from wooden master patterns using **double shrink.** For example, if a gray iron production pattern is to be used in producing aluminum alloy castings, the wooden master pattern is made with a $\frac{9}{32}$-inch shrinkage rule ($\frac{5}{32}$ inch for aluminum alloy plus $\frac{1}{8}$ inch for gray iron). One-eighth inch per foot of this double shrink allows for the shrinkage that takes place as the gray iron production pattern solidifies and cools. The production pattern is still sufficiently oversize to allow for the $\frac{5}{32}$ inch per foot of shrinkage that will occur as the aluminum alloy casting solidifies and cools.

Allowance for Machining (Finish)

Another reason for making patterns somewhat larger than the finished casting is to allow for machining (removing extra metal). Specific areas where the casting will be machined are identified, and additional material is added to the pattern in these areas.

PATTERN SHOP MATERIALS

Lumber

Patternmakers prefer to use woods that can be worked easily with hand or machine tools. Wood should also be stable, straight grained, of even texture, dense, and soft to medium in hardness. Most important, it must be properly cured. It must also be acclimatized by being stored long enough to adjust to the **average moisture content** of the area. (For most of the United States, this is 8 percent; in the southeastern states, it is 11 percent.)

Occasionally a hard dense wood such as cherry is needed. Otherwise, the most commonly used woods for patternmaking are:

- White pine (western sugar)
- Mahogany (Mexican, Honduras, or Peruvian—*not* Philippine)
- Jelutong (from Malay)

Adhesives

A number of different glues or adhesive materials have been used for patternmaking. At present, unless special conditions require a different glue, the most common glue used by patternmakers is white glue. This is a ready-to-use, polyvinyl resin emulsion glue. It comes in plastic squeeze bottles and is sold under a variety of registered trade names. Patternmakers also use a cream-colored aliphatic formulation of this glue, known as professional carpenter's glue. It has a stronger initial tack and shorter cure time. Both of these glues are very useful, but both cause rust when brought into contact with iron and steel.

Epoxy adhesives should be considered when exceptionally secure bonding to almost any material is required. Epoxy adhesives consist of two parts, kept separate until used. Equal amounts of part A (resin) and part B (hardener) are mixed thoroughly. When the material is an even color without streaks, the adhesive is ready to apply (working time is usually less than 30 minutes and sometimes much shorter). The assembly is held in position (with light clamping) until cured. Follow directions on container.

Dowels

Dowels are used to guide and hold separate portions of foundry tooling in their proper positions on a temporary or permanent basis. At least two dowels are used at a time. They are commonly installed so that incorrect assembly is obvious. For example, dowels of different diameters are used (Fig. 2-3) or dowels of similar diameters are used with one placed ½ inch

Figure 2-3
Dowels of different diameters prevent incorrect assembly of a corebox.

(12.7 millimeters) from the left side and another 1 inch (25.4 millimeters) from the right side of the part. Dowels should be installed *early* in the construction of the article. If you wait until the parts are completed, installing dowels so that the parts align perfectly is an extremely difficult task.

Wooden Slip-Fit Dowels: Slip-fit dowels should have the working ends shaped as shown in Figure 2-4. The tapered portion of the dowel locates and guides the assembly. The ⅛-inch shoulder provides the final alignment or register. The relatively small amount of contact provided by the ⅛-inch shoulder with the hole in the mating part facilitates separation of the parts. Wooden dowels of this shape are vastly superior to slip-fit dowels with working ends that are unshaped or only slightly chamfered on the end.

Wooden Press-Fit Dowels: A different application of wooden dowels should not be overlooked: Alignment and *permanent* fastening of pattern parts to a plate often is accomplished with press-fit dowels. Trial holes in scrap wood are made to ensure a snug fit of the dowel in the hole. Two shallow lengthwise kerfs on opposite sides of the dowel allow air and excess glue to escape when the dowel is inserted into a hole. When properly installed, the dowel fits through the hole in one half of the pattern, passes through the plate, and protrudes into a blind hole in the other half of the pattern.

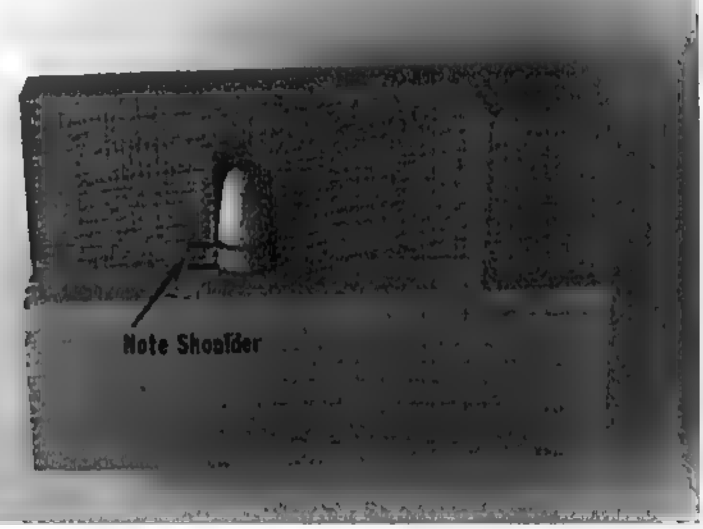


Figure 2-4
A properly shaped wooden slip-fit dowel—only the shoulder should touch the hole.

Brass Dowels: Brass dowels are preferred for slip-fit applications with wooden patterns and coreboxes. They come in different sizes, which are indicated by numbers. Number 2 dowels, which are installed in ¼-inch diameter holes, meet many school foundry needs. A special installation tool (available from the supply house where the dowels are purchased) is required for each size dowel (Fig. 2-5). The installation tool is used to screw the dowels into place. The special threads on the dowels are self-tapping and will seat themselves in soft woods without countersinking. A little soap or wax on the threads makes installation easier. In industry, many metal pattern and corebox parts are aligned with special alloy steel dowels that have been hardened and treated for rust prevention.

Fillet Materials

The inside corners of a pattern are seldom left square. To do so would create a hot spot and result in shrinkage cracks in the corner of the casting. To avoid this, the patternmaker places material in the corner to form a fillet (Fig. 2-6). Fillets also make it easier to remove the pattern from the mold. A number of materials are used.

Wood Fillet: Many patternmakers can remember when they laboriously carved fillets from wood that had been left in the corner of the pattern for that purpose. The carving of integral wood fillets is seldom

Figure 2-5
A special tool is required to install brass dowels.

done today. Limited use is made of wood fillets that are available commercially in many sizes. They are nailed and glued in place.

Wax Fillet: Wax has long been used and still is used with wooden master patterns. It is inexpensive and quite easy to install. Installation tools consist of an alcohol lamp, a ball-end fillet tool, and a scraping tool. The back of the wax fillet is melted slightly over the flame of the alcohol lamp,

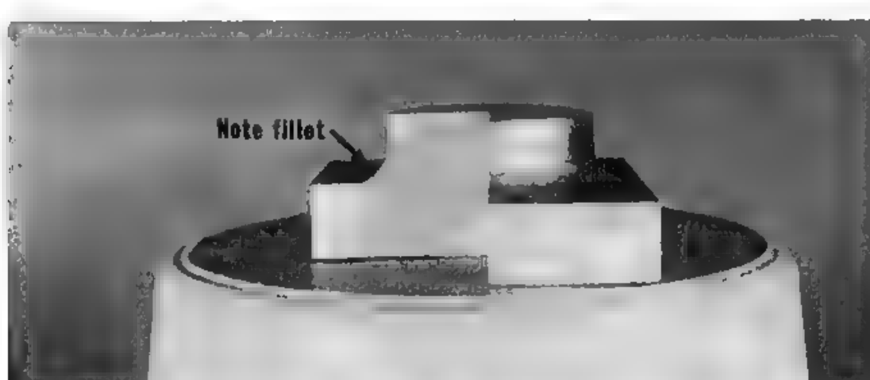


Figure 2-6
Close-up of a fillet.

Figure 2-7
Rubbing wax fillet into an inside corner with a warm fillet tool.

and the fillet is rubbed into the corner with a proper size fillet tool (Fig. 2-7). Any surplus is removed with the scraping tool.

NOTE: The fillet tool is used most effectively by *rolling* the ball end of the tool as pressure is applied to the fillet material.

Leather Fillet: Leather is another material that, like wax, has seen much use and continues to be used in some applications. It can be stretched or contracted slightly, and it handles curves well. Dipping the leather fillet into alcohol or lacquer thinner (allowing the liquid to evaporate before applying glue) makes the leather more pliable for short radii and sharp turns. When properly installed, leather provides a surprising amount of strength. A liberal amount of glue is applied to the soft, porous side, and it is rubbed into the corner with a proper size fillet tool.

Plastic: Extruded plastic fillet material is a more recent, relatively inexpensive material that lends itself to certain applications. A special adhesive is applied to the back of the fillet *and* the inside corner of the pattern. After this is dry to the touch, the fillet material is pressed into place with the fingers. Accurate placement is critical since the fillet adheres on contact. There is little or no opportunity to make slight adjust-

ments. Its promoters claim that use of plastic can save as much as 50 percent of the cost of other fillet materials.

NOTE: All the above fillet materials are available commercially in many sizes. Fillet sizes are based on the radius of the fillet in sixteenths of an inch. For example, a No. 4 fillet would have a radius of 4⁄16 inch (or ¼ inch).

Polyester Putty: The newest and most used fillet material is very similar to body putty used in auto repair (Fig. 2-8). It is generally a two-part system, a quart of resin and a small tube of hardener. When thoroughly mixed together in proper proportions (follow directions on can), the material must be used immediately. It is placed into a corner and smoothed (rolled) into fillet shape with a proper size fillet iron. Extra material that squeezes out beyond the fillet can be peeled off while it is still rubbery, before final set.

NOTE: Dipping the fillet iron in lacquer thinner or water will help to achieve a nice, smooth fillet. Remember to *roll* the tool.

ONE FINAL NOTE: Very small fillets are often produced with a reasonably heavy coat of pattern paint.

Figure 2-8
Plastic fillet material—often used in present-day pattern shops.

Plasters

Plasters are used for producing patterns, molds, and models and for making proof castings, for example, to check the accuracy of a corebox. There are numerous gypsum plasters available to the patternmaker. The plaster of paris of earlier times has been replaced by super-strength gypsum cements known to patternmakers as hard plasters. These are about *five* times as strong as ordinary plasters. They are engineered materials, and care should be taken to select the most appropriate one for the specific job. They are available in different strengths and densities, and various rates of expansion and degrees of workability. Setting times usually are in the range of 20 to 30 minutes, but some materials can be extended with the addition of a setting retarder. Parts produced from such plasters are usually stable and dimensionally accurate, with little tendency to absorb moisture. Some plasters, when dry, can be machined. Surface hardness, tensile strength, and compressive strength often can be varied by using different amounts of mixing water.

When mixing plasters, always follow the specific directions provided by the manufacturer or supplier. Generally, you should:

1. Weigh plaster and water (30–40 pounds of water per 100 pounds of plaster—or follow instructions if available).

NOTE: Using hot water (140–150F) will speed up the process and reduce all times given below.

2. Add plaster to water a little at a time until all has been added. Let it soak for 2 to 3 minutes.
3. Mix thoroughly for 2 to 5 minutes until slurry has *creamed* (thickened slightly).
4. Pour into one corner of the flask so the plaster will flow smoothly across the pattern.
5. Rap the flask or use a vibrator or vacuum table to work out air bubbles and ensure reproduction of fine detail.
6. Remove from mold when completely set (40–60 minutes after pouring).

In addition to pouring, many plasters can be shaped by screeding or splash casting. More detailed information on this subject is available from manufacturers or suppliers of hard plasters or in books on patternmaking, such as the AFS publication *Patternmaker's Manual.*

Plastic Materials

A number of plastic materials are used to good advantage by patternmakers in producing foundry tooling. The use of polyester putty to pro-

duce fillets has already been mentioned. It will be covered here in more detail. So, too, will other plastics and the ways in which they are used to produce foundry tooling that is hard, dense, and corrosion- and abrasion-resistant. Also, common procedures of working with these materials will be provided.

Polyester Putty: This has become an almost universally used repair and build-up material. It adheres to any material; roughening the surface by sanding wood or sandblasting metal increases holding power. Wiping with a cloth moistened with alcohol ensures a clean, degreased surface, which is essential. Mix the ingredients thoroughly according to directions on the can. Too much hardener will shorten working life; too little will extend set time. After mixing, the material must be put in place promptly before it starts to set. Be neat—after polyester putty has set, it is *much* harder to remove than it was to apply. Slight shrinkage in holes and deep recesses may require a second application. When the putty starts to set, it goes through several stages. After it has set beyond the crumbling or tearing stage, it can be carved easily. Later, after final set, it still can be carved, but with more difficulty. From this point on, it can be sanded. *Do not breathe the dust.* Wear a filter mask or work where ventilation will move the dust *away* from your breathing zone.

Castable Plastics: Many liquid plastics are commercially available under registered trade names. Castable plastics are used to produce tooling that is subject to longer production runs than wood tooling can tolerate and shorter runs than cast iron tooling can handle. Such plastic tooling is less expensive than metal tooling, is stronger and more stable than wood tooling, and can be repaired or changed easily. Tooling from castable plastic can be machined with metal-cutting equipment, but carbide-tipped cutters are preferred.

Corebox Vents

Vents used in coreboxes come in a variety of sizes and types. Each type and size of vent is available in a range of slot or mesh sizes. Vents are made of brass, aluminum, or nylon. Some milled-slot vents can be shaped, after insertion, to fit the contour of the box. Vents are chosen with openings slightly smaller than the size of the grains of sand that are to be used. Vents that are easy to clean are preferred. Specialized tools that simplify the drilling and inserting of corebox vents are available, but such tasks, if done carefully, can be accomplished without them.

Pattern Letters and Figures

Preformed letters and figures are available for making patterns. These come in a variety of sizes. They are made of white metal (lead- or tin-

Figure 2-9
Pattern letters and figures.

base alloy), brass, or aluminum. They have plain backs, sprigs, or spurs (which are pressed into the wood) or are drilled for attaching with brads. They can be *"right-reading"* or *"reverse"* (Fig. 2-9). A number of methods are used to fasten letters with plain backs to patterns. Special cements are available to hold them permanently. Several small drops of white glue (applied with a toothpick) will work for many school foundry applications.

Pattern-Finishing Materials

The surfaces of foundry tooling that come in contact with sand must be smooth and free of small imperfections. Wood, metal, or plastic materials that are not sufficiently smooth are filed and then sanded with abrasive cloth or paper several times, in decreasing grit sizes, until all tool marks, roughnesses, and other imperfections are eliminated. Shrinks or other low areas are filled with polyester putty and sanded smooth. Then these surfaces usually are painted or treated in one or more ways.

Pattern Paint: Wood patterns and coreboxes must be sealed or contact with moist sand could cause changes in size and shape. Also, the surface of the pattern must be as smooth as possible so that moist sand does not stick to it. Varnish, shellac, and lacquer have all been used to coat pat-

terns, but each has serious disadvantages. The coatings used most today are aluminum-based paints of the evaporative nitrocellulose type. They are available commercially in a variety of colors. They can be thinned for seal (primer) coats and for a smooth, glossy, final coat. Intermediate coats can be heavier to fill grain or produce small fillets. At least three coats are recommended. Such paint is commonly kept in a paint pot with the bristles of the brush immersed. This keeps the bristles pliable and always ready for use. The paint should be applied with minimum brushing. It dries enough to be handled in about 30 minutes.

Metal foundry tooling does not require the stabilizing effect of paint. Paint does, however, assist metal tooling in achieving good release from the sand just as it does with wood tooling.

Metallic Coatings: Coating the surface of wood foundry tooling by metallizing, or aluminum tooling with a layer of harder metal, can reduce abrasive wear and extend tool life. Electroplated chromium produces a layer that varies in thickness. An electroplated nickel coating is uniform, but too soft to be useful.

The metallic coating that best meets the needs of foundry tooling is known as electroless nickel. This process is quite different from standard plating practices since no electricity is used. Coatings are quite uniform. They average 0.003–0.005 inch (0.08–0.13 millimeter) in thickness and can be controlled to within ±0.0001 inch (0.0025 millimeter). They are nonporous and corrosion- and abrasion-resistant with a hardness of 48–50 Rockwell C (RC) and as slippery as a wet bar of soap. The hardness can be increased to 70 RC by postbaking at temperatures of 550–750F (287–348C) if the substrate can withstand such temperatures without distorting. The low coefficient of friction (degree of slipperiness) may be as important as hardness in increasing tool life.

Tin and zinc alloys *cannot* be coated. Magnesium *can* be coated, but special procedures are required. Other common metals, even ferrous/nonferrous combinations, can be plated successfully with electroless nickel.

Electroless nickel has made its most dramatic contribution to low-cost foundry tooling in its ability to coat epoxy patterns. Such tooling is estimated to be 20 percent of the cost of comparable iron tooling and 30 percent of the cost of comparable aluminum tooling. These cost benefits are achieved without a sacrifice in performance. In addition, tooling made of combinations of metal and epoxy parts can be coated as if only one material were involved.

Electroless nickel can also be used to coat sprayed metal tooling (of zinc and tin alloys), which is described on p. 59. All surfaces of the sprayed metal tooling first must be copper plated; the tool then is coated with electroless nickel in the usual way. Such a coating would increase the life of the tool substantially, especially under highly abrasive conditions.

WOOD PATTERNS

Layout

Layout of wood patterns must be done very accurately and with careful planning. Complete patterns are often laid out, full-size, on the wood. The left and bottom edges of the wood should be square (at a 90 degree angle to each other) and accurate so that a framing (or other) square can be used to make accurate layout lines. Make lines with a sharp pencil or knife. Make knife lines more visible by running a sharp pencil in the knife groove.

Use the following procedure:

1. Select the parting line.
2. Determine necessary cores or loose pieces, if any.
3. Make a full-size layout with correct size shrink rule.
4. Add draft.
5. Add finish allowances (color, such as red, helps here).
6. Add core prints if necessary (yellow).

Solid versus Glued-up Patterns

Sometimes a pattern is made of a single piece of wood. More often two or more pieces are glued together. This is done to produce a piece of sufficient size and/or to help control changes in size and shape. Also, most patterns are constructed by assembling preshaped *pieces* rather than by shaping the pattern from *solid stock.*

Lathe-Turned Patterns (Between Centers)

Patterns of long, cylindrical configuration are turned to shape between the centers of a lathe. Usually, the pattern must be two exact, lengthwise halves, rather than a solid turning. When making such patterns

1. Use two pieces of wood fastened together with a **paper/glue joint** and/or wood screws installed in waste material at ends of stock (Fig. 2-10).
2. Locate the center of each end very carefully on the joint.
3. Drill and install dowels *before* turning.
4. Provide for draft and integral fillets as the piece is turned.

Figure 2-10
Foreground: Pieces ready to be assembled into a paper glue joint. *Background:* Pieces assembled for turning with screws in waste stock.

Loose Pieces

Some patterns or coreboxes have essential components called **loose pieces.** There are four categories of loose pieces. Two of these, attached and stopoff, promote efficiency and/or reduce tooling costs. The other two, **drawbacks** and **pickouts,** sometimes provide the only way a pattern can be drawn cleanly from the sand. Figure 2-11 illustrates drawbacks. The use of drawback and pickout loose pieces to solve molding or coremaking problems is ingenious, and requires ingenuity in the manner in which these loose pieces are held securely in place but still can be removed easily. Slip-fit dowels, dovetails, tapers, and wedges are just some of the means by which this is accomplished.

Woodworking Machinery

All the woodworking machines are used by the patternmaker, but the two most valuable are the disk sander and the spindle sander. Both should have tilting tables. Extremely small amounts of material can be removed with these machines if you are a skillful woodworker and have a steady hand.

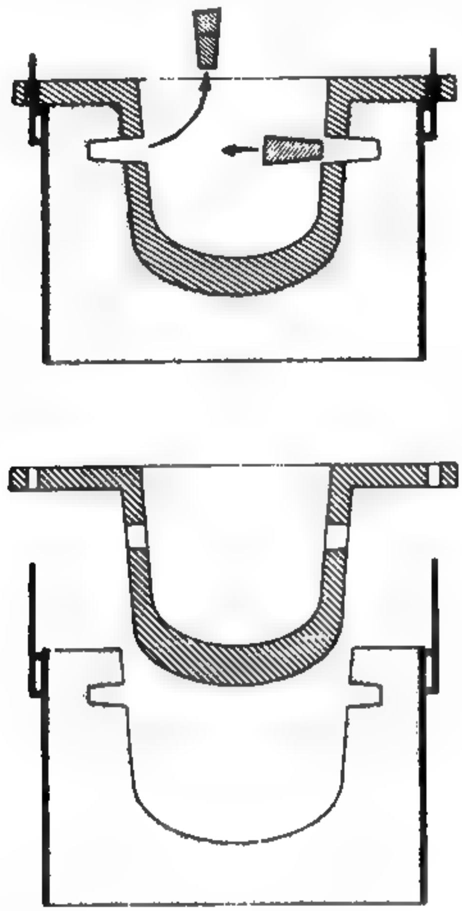


Figure 2-11
The loose pieces (drawbacks) are removed through a hole in the matchplate. The matchplate can then be removed from the drag.

MATCHPLATES

An unmounted pattern is called a **loose pattern.** Such patterns can be flat back, hollow back, split, or irregular parting line. They are seldom used in industry except for making prototypes or small numbers of large castings. They are, however, commonly used in school foundries where they have some value in teaching basic molding procedures. If instruction in school foundries is to be representative of industry, most castings made in school foundries should be made from patterns mounted on plates.

There are several types of pattern plates. A technical distinction can be made between **plain plates, matchplates, composite plates, cope plates, drag plates,** and so on. For our purposes, a matchplate will be considered a plate (metal or wood) with the pattern and most of the gating system permanently attached to it (Fig. 2-12).

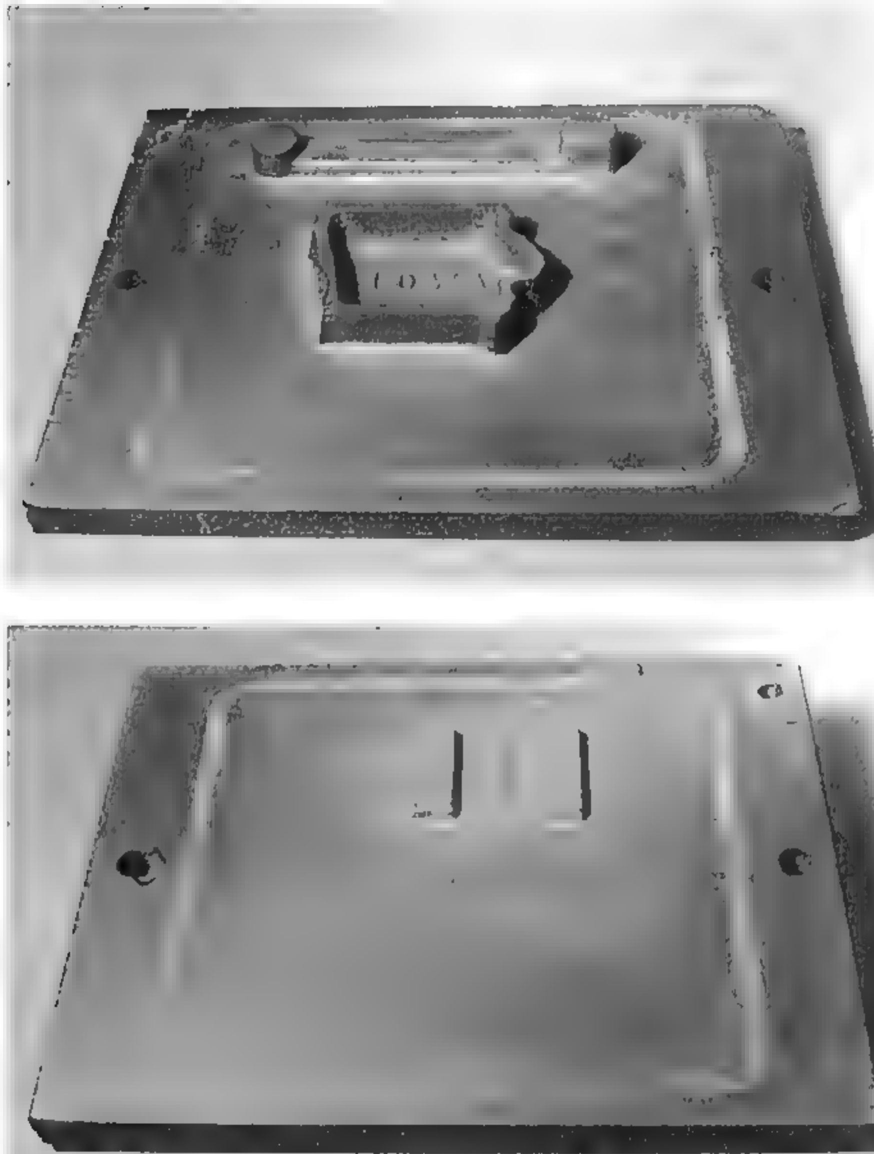


Figure 2-12
Top, Drag side of matchplate with pattern, sprue base (*upper left*), tapered runner, and runner extension. *Bottom:* Cope side of matchplate with two gates.

Matchplates provide many advantages over molding with loose patterns, some of which are:

- Better quality castings—withdrawing the matchplate from the sand with the flask pins serving as guide pins is much easier than drawing loose patterns and ensures minimum mold damage.

- Greater efficiency—matchplates enable molders to put up many more molds than can be made with loose patterns (eliminating the need to cut runners and gates accounts for much of this increase in efficiency).
- More consistent size of castings—much less variation in mold size occurs when matchplates are vibrated than when loose patterns are rapped to free them from the sand.
- Fewer loose-sand defects in castings—hand-cut sprue bases and runners and gates made with loose patterns result in more loose sand than do molded gating systems produced by matchplates.
- Longer pattern life—matchplates are easier to use and store without damage than are loose patterns.

Fabricated Matchplates

An industrial matchplate usually consists of the pattern, sprue base, and runners and gates cast as an integral part of the plate. Some matchplates, however, are fabricated; that is, a number of different materials are used to produce the various components.

Plate Material: Matchplates used in school foundries commonly are made by mounting the pattern(s) and the gating system parts mentioned above on a piece of plywood. The plywood should be at least ¾ of an inch (19.5 millimeters) thick. White pine or birch veneer plywood rated *G2S* (good two sides) works well. Plywood with a lumber core is preferred, but veneer or particle-board core plywood is certainly satisfactory. Formica® covered plywood pieces that are the result of cutting an opening for a sink in the top surface of a kitchen cabinet are sometimes available to school foundries at low or no cost. Such pieces are ideal because of their hard and durable surfaces. Some special plywoods such as U.S. Plywood's Duraply® are preferred by commercial pattern shops.

Sizing the Plate to the Flask: Select a flask that will provide 1–2 inches (25.4–50.8 millimeters) of sand between the flask wall and the pattern. Cut the plywood plate 2 inches (50.8 millimeters) wider than the inside width and 6 inches (152.4 millimeters) longer than the inside length of the flask. Center the flask on the plate.

Fitting the Plate to the Flask: Students often install the pattern(s) and gating on a matchplate and *then* fit it to the flask. If incorrect size holes for the flask pins are bored or mistakes are made in spacing the holes, much time is lost in reclaiming a useless matchplate. It is better to get a proper fit of the plate to the flask before you have invested so much time.

Industrial flasks, many of which are removable from the mold, often have two round pins at each end of the flask or some other pin and guide arrangement. Most flasks in the school foundry have a single round pin at each end of the flask. It is critical that the holes in the plate be sized and spaced to permit the plate to be drawn smoothly. Occasionally, plates are fitted to a specific flask with two holes, one at each end. More often, a hole and a slot are used to accept the variation in pin spacing in flasks of the same size. The hole (or width of the slot) should be 0.005–0.010 inch (0.13–0.25 millimeter) larger than the pin. This is not much and should be achieved very carefully. If available, a round file (the same size as the flask pin) designed for use on a filing machine can be rotated by hand in the hole or worked longitudinally in the slot to provide the small amount of clearance needed.

Hole and Slot:

1. Place the cope on the plate with equal space at both edges and ends.
2. Draw a line completely around the flask using the inside edge of the flask as a guide.
3. Use a flask pin that has been machined to a point (standing perfectly straight in the bushing of the cope) to locate the center for the holes to be drilled at each end of the flask.
4. Draw a line between the two points established above.
5. On this line place a punch mark ¼ inch (6.35 millimeters) to the left and right of the original mark at the *right* end of the plate.
6. Drill the hole located at the left side of the plate and *two* holes centered in the punch marks made at the right side of the plate (Fig. 2-13). Use a drill press and spur machine bit of the same size as the flask pins.
7. When the two small triangles of material between the two holes on the right have been removed by filing and the necessary 0.005–0.010-inch (0.13–0.25-millimeter) clearance has been achieved, the plate should fit flasks of the same size regardless of variation in pin spacing.

NOTE: A vertical milling machine could be used. It is especially helpful when plates are of metal.

Two Holes

1. Carry out the first three steps above.
2. *Drill trial holes in a scrap strip of wood.* Use a drill press and a spur machine bit of the same size as the flask pin.

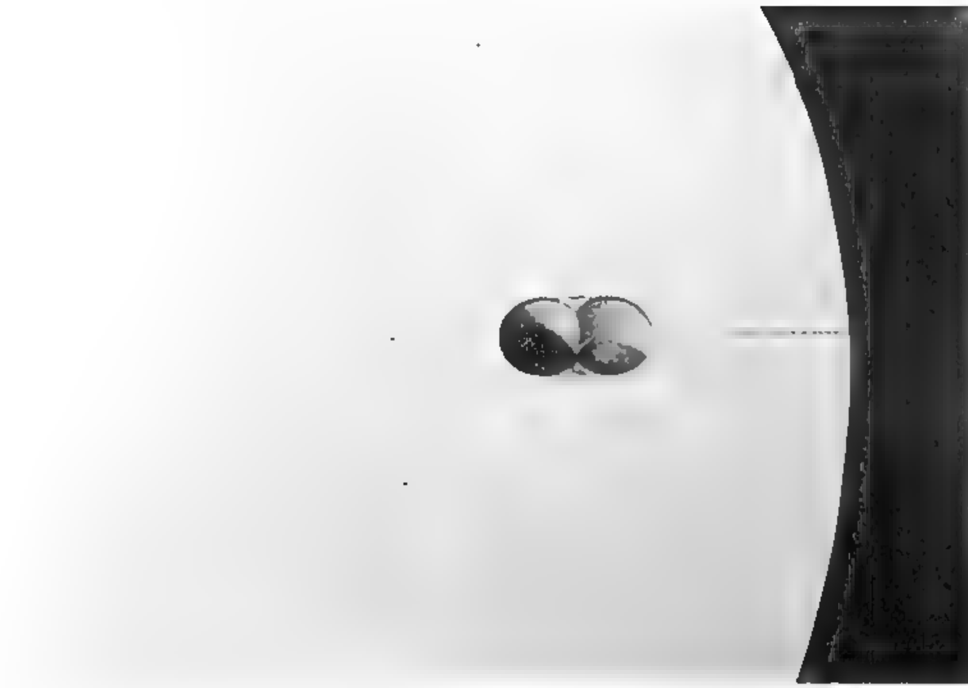


Figure 2-13
Producing the slot for a hole-and-slot matchplate. The triangles of material between the holes are removed carefully with a file.

3. Verify that the spacing is accurate or modify spacing and try again. When spacing is accurate, clamp the trial piece, properly located, to the plate and use it as a drill guide.
4. Drill holes.
5. File carefully to secure necessary clearance.

NOTE: Flask pin guides, small pieces of metal with highly precise holes and slots, are sometimes installed at each end of a plate. They are mounted on top of, or flush with, the plate above oversize holes (Fig. 2-14). The guides should be held securely, with cap screws in threaded holes or with washers and nuts through holes. Flask pin guides provide wear resistance, smoother operation, and possibly, an opportunity to make slight adjustments in hole spacing. Sometimes it is possible to use flask pin guides to reclaim a matchplate that has been rendered useless with incorrectly spaced or sized holes. Remember, however, that the flask pin guides must be installed with more care and precision than was used in the previous attempt to fit the plate to the flask.

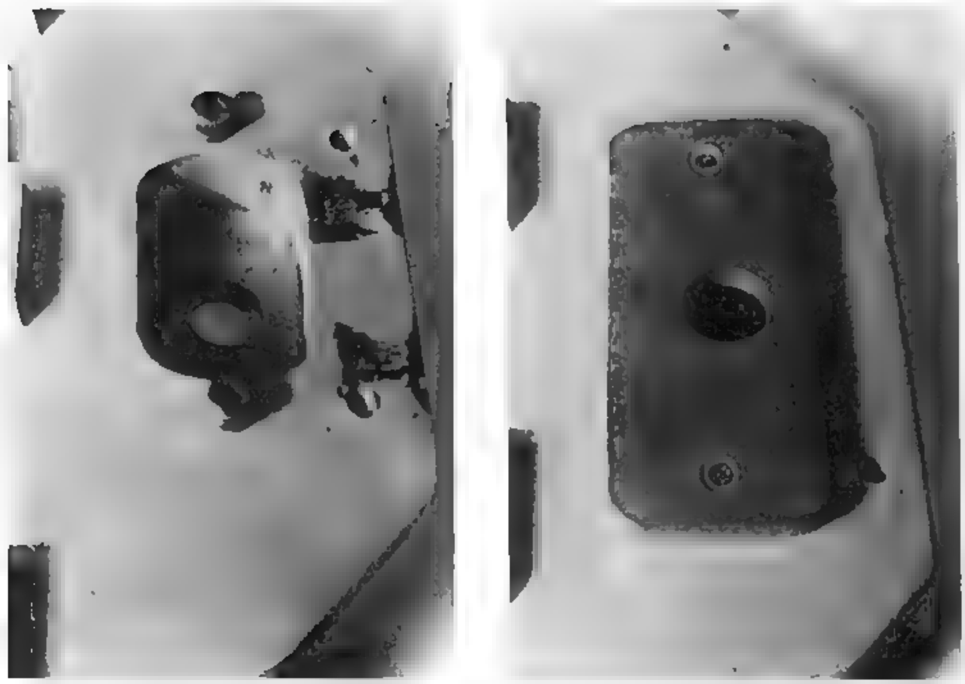


Figure 2-14
Left: Oversize hole in matchplate and flask pin guide held securely in place with cap screws. *Right:* Underside of flask pin guide.

Installing Patterns on Plates: Bench blocks, two wooden four by fours of appropriate length, support the plate during layout and installation of patterns. Plates containing flask pin guides can be accommodated with centrally located cutouts in the top of the blocks (Fig. 2-15). The pattern, together with the sprue base, runner(s), gates, and runner extension(s), should be positioned to use the available space to its best advantage. When possible, the sprue base should be close to a side or end of the flask rather than in the center.

Good layout techniques are essential. This task is reasonably simple if the whole pattern is to be mounted on one side of the plate. The task is complicated if part of the pattern is to be on one side of the plate and the rest of the pattern on the other side. This is a common arrangement with split patterns (Fig. 2-16). The pieces must be located directly opposite each other or poor registration from a mismatch of pattern halves will result. Squaring one or more reference lines completely around the plate (i.e., surface, edge, surface, edge), if done carefully, provides some confidence that pattern halves are placed correctly. However, a more popular technique is to use press-fit dowels that go through one pattern half, through the plate, and into the other pattern half. The through-drilled

Figure 2-15
Cutouts in the tops of bench blocks will accommodate flask pin guides.

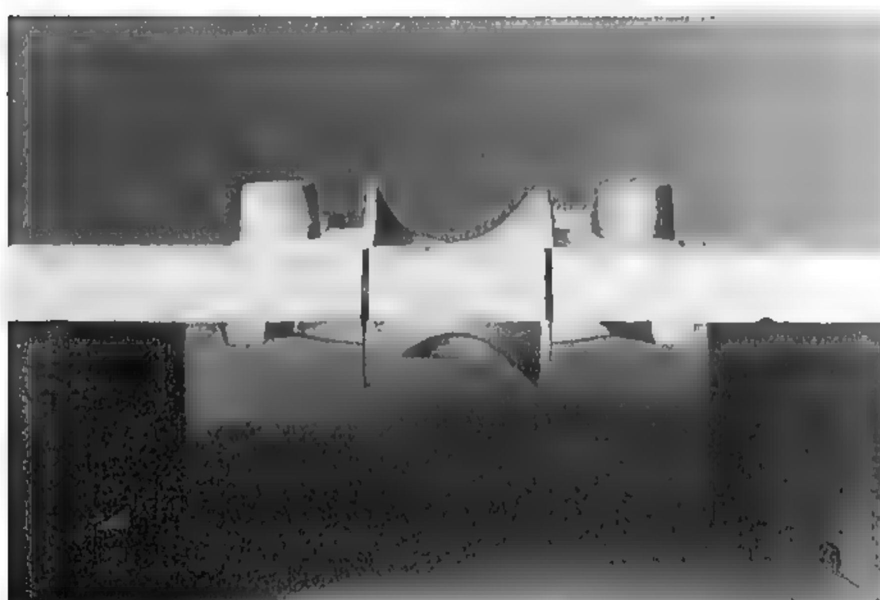


Figure 2-16
It is essential that split patterns be mounted precisely opposite each other on a matchplate. Reference lines will enhance accuracy.

pattern half is positioned and clamped to the plate. It is used as a drill guide.

NOTE: After drilling, the pattern half is removed and the holes in the plate are enlarged with the next *larger* size drill bit. This provides clearance so that perfect alignment of the pattern halves can be achieved with press-fit dowels in spite of any drifting of the drill when making the original holes.

The pattern halves are then assembled (with dowels) on each side of the plate and any holes that remain are plugged with polyester putty. The dowels will align and provide some holding power, but the pattern pieces should be attached securely to the plate. Flat-head wood screws for wood patterns and machine screws (for metal) are commonly used in industry, where matchplates occasionally require modification. In school work, if no changes are required the pattern and other pieces can be permanently attached with glue. White glue, epoxy resin, or contact cement can be used.

The top part of a flask is the cope and the bottom part is the drag; similarly, the surfaces of the matchplate are named for the *parts* of the flask they *touch*. Whole patterns are almost always mounted on the drag side of the matchplate together with the sprue base and runner(s). Gates are mounted on the cope side.

Casting a Matchplate

Many industrial matchplates made of aluminum are pressure cast in plaster molds. One of the quickest and simplest ways to produce a matchplate for school use is to cast it in a green sand mold. Mold a loose pattern in the usual manner but in an extra large flask. Be sure the gating system is properly designed and that all runners and gates are smooth. This is best achieved by using fabricated gating system pieces. Take special care to see that the parting surfaces of the cope and drag are flat and smooth. Before the mold is closed for pouring, place a frame made of ⅜-inch mild steel (Fig. 2-17) on the drag. The cope is then placed in position so that its parting surface comes to rest on the frame. Be sure to melt plenty of metal. When this mold is poured, the resultant casting will be a ⅜-inch thick plate with the pattern and gating system cast as an integral part of it (Fig. 2-18). The only additional processing required is to remove the sprue at the sprue base, make holes in the ends of the matchplate to permit it to slide smoothly over the pins of the drag, and drill a hole for attaching the vibrator. Any surface imperfections can be filled with polyester putty and smoothed down. A coat of pattern paint will add a finishing touch.

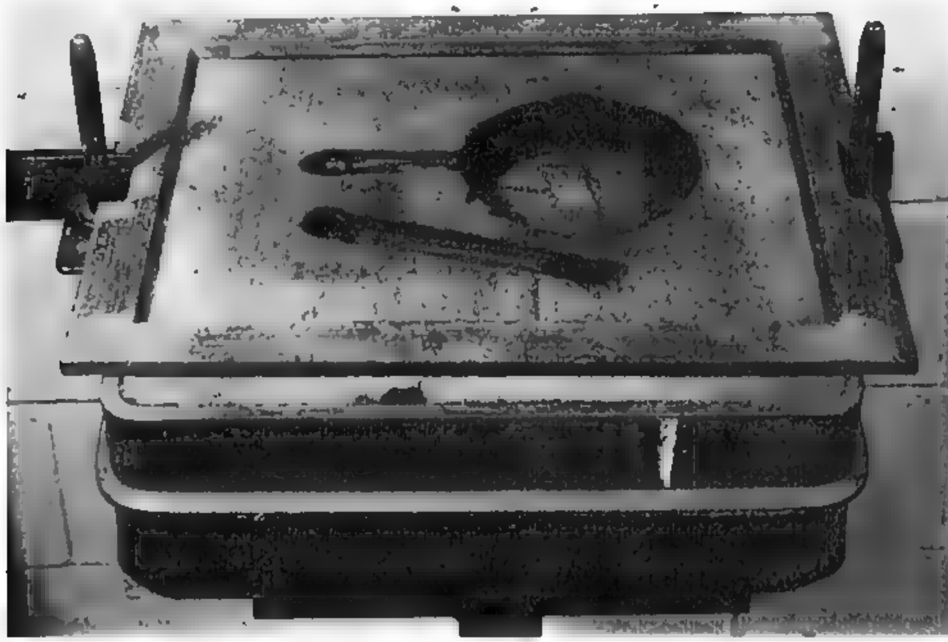


Figure 2-17
A frame of ⅜-inch mild steel is placed on the drag before closing the mold.

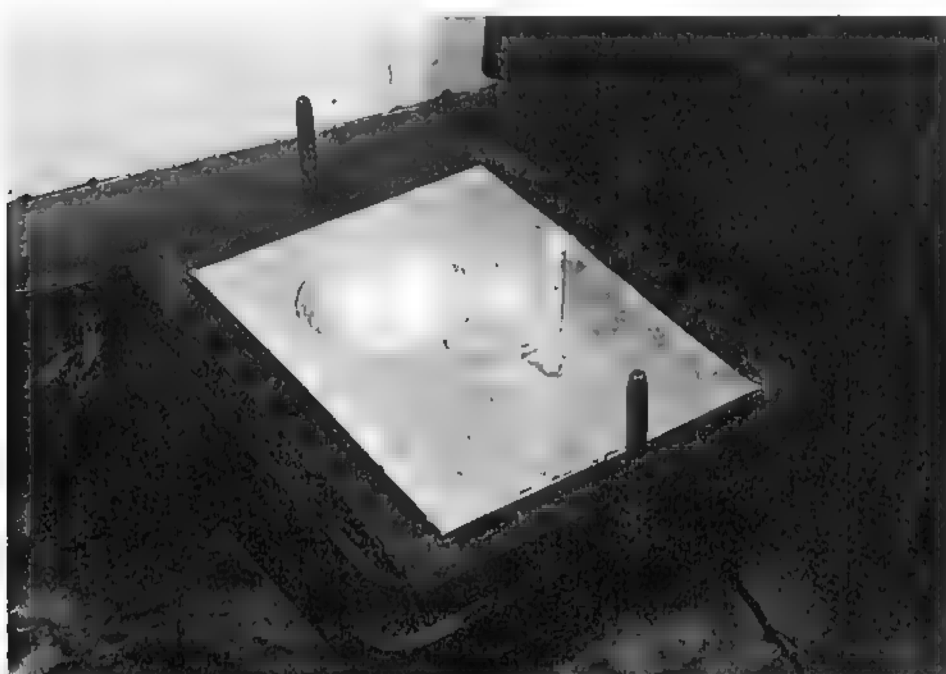


Figure 2-18
Plate, pattern, and gating have been poured as an integral unit.

COREBOXES

Coreboxes are an important part of foundry tooling. Unless castings are quite simple, they usually require one or more dry sand cores. These cores are shaped in coreboxes. Coreboxes, like patterns, are laid out with the appropriate shrink rule, depending on the metal to be cast. Symmetrical cores may be made in halves and pasted together. This is a common technique with oil sand cores. Such cores have to be properly supported until they are baked. Making them in halves permits a simple, inexpensive, flat metal plate to be used for support. Otherwise, an expensive device (**core drier**) that is specially shaped to support the outside configuration of the core must be used in baking. With this exception, coreboxes are commonly designed to produce a complete core rather than only half of one. Such boxes are often used on machines (**core blowers**) that utilize air pressure to fill and pack sand in the core box (Fig. 2-19). Such boxes must have vents to allow the air in the box to escape as the sand enters. Coreboxes that must withstand a great deal of abrasion are made of

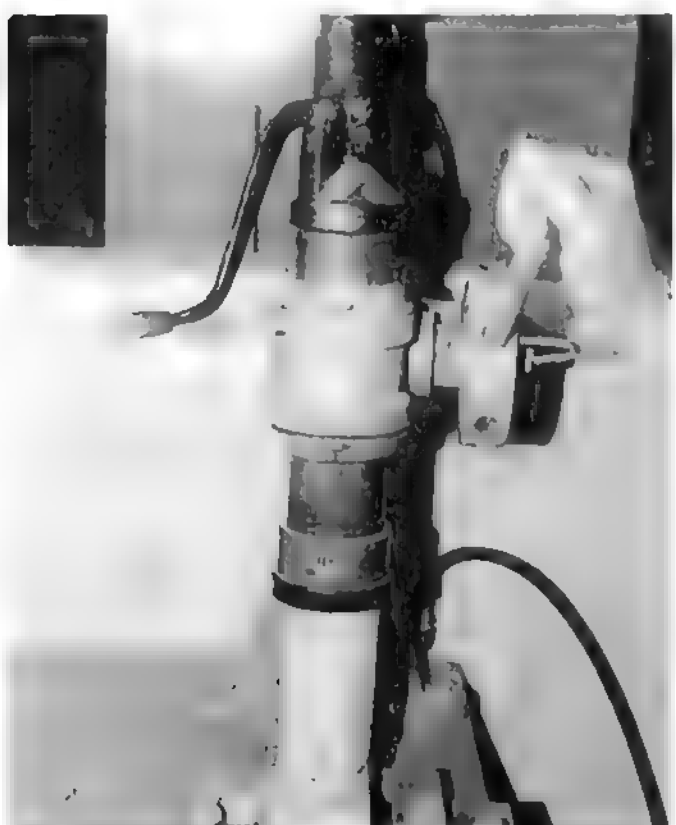


Figure 2-19
A bench-type core blower.

metal. So, too, are boxes that are heated for making cores with plastic-coated sand that responds to the heat of the box by first softening and later hardening, locking all sand grains together and producing a core the shape of the cavity.

Simple Cylindrical Coreboxes

Following are the steps necessary to produce a 1-inch diameter by 4-inch (25.4 by 101.5 millimeters) core.

1. Use the proper shrink rule for all layout work.
2. Square up two pieces of wood, 1 inch by 2 inches by 4½ inches (25.4 by 50.8 by 126.9 millimeters). Be sure ends are square.
3. Clamp together and drill for slip-fit wooden or brass dowels. Plan for all dowels to point in the same direction and to be placed along only *one* edge.
4. Install dowels (Fig. 2-20).
5. Mark location for drilling on end—center of 2-inch (203-millimeters) width on parting line.
6. Clamp together and stand on end.
7. Drill with 1-inch spur machine bit completely through workpiece into scrap wood.

NOTE: This should provide an accurately machined cylindrical cavity with exactly one half of the cavity in each piece. There are other ways of producing such a cylindrical opening, but for short cores this method is probably the easiest and quickest.

NOTE: A similar shape for longer cores can be produced by drawing a half-circle on the end of each piece of stock and using a circular saw. Adjusting the fence to different widths and the saw blade to various depths enables a series of saw kerfs to be made. This removes most of the material. The rest of the material is removed down to the layout line by hand with a gouge. Remove tool marks with sandpaper wrapped around a dowel rod of the appropriate size.

NOTE: Another approach is to use a circular saw set up to do cove cutting. If a 2-inch (50.8-millimeter) diameter core is needed, the blade is set to one half the depth of the core, 1 inch (25.4 millimeters). A parallel rule, set to 2 inches (50.8 millimeters), is placed over the blade and angled until each rule is touched by a tooth at the front and rear of the saw blade. An auxiliary wood fence is clamped to the saw table at this angle so that when the

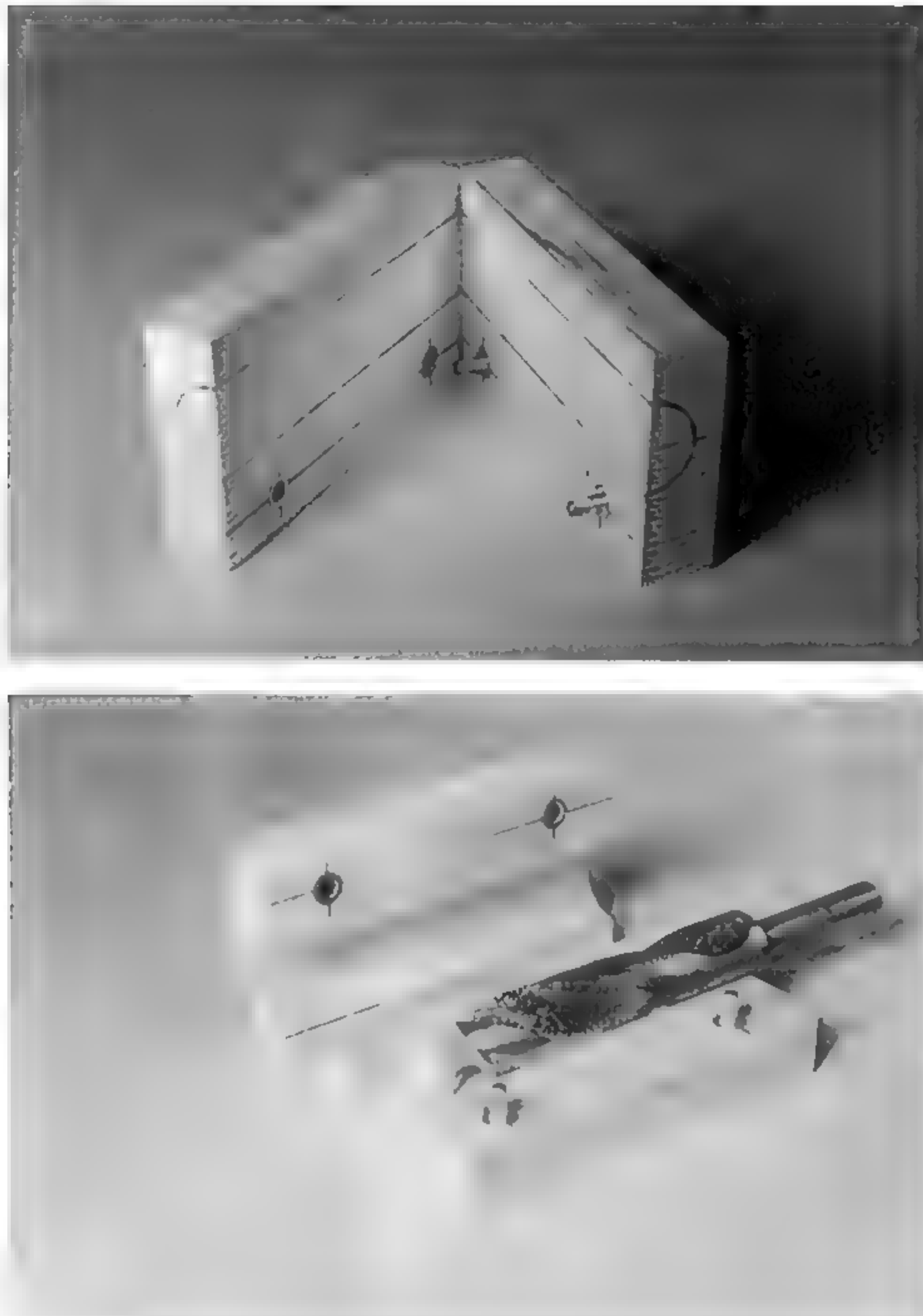


Figure 2-20
Construction of a simple cylindrical corebox. *Top:* Pieces laid out, dowels installed, ready for clamping and drilling. *Bottom:* After drilling.

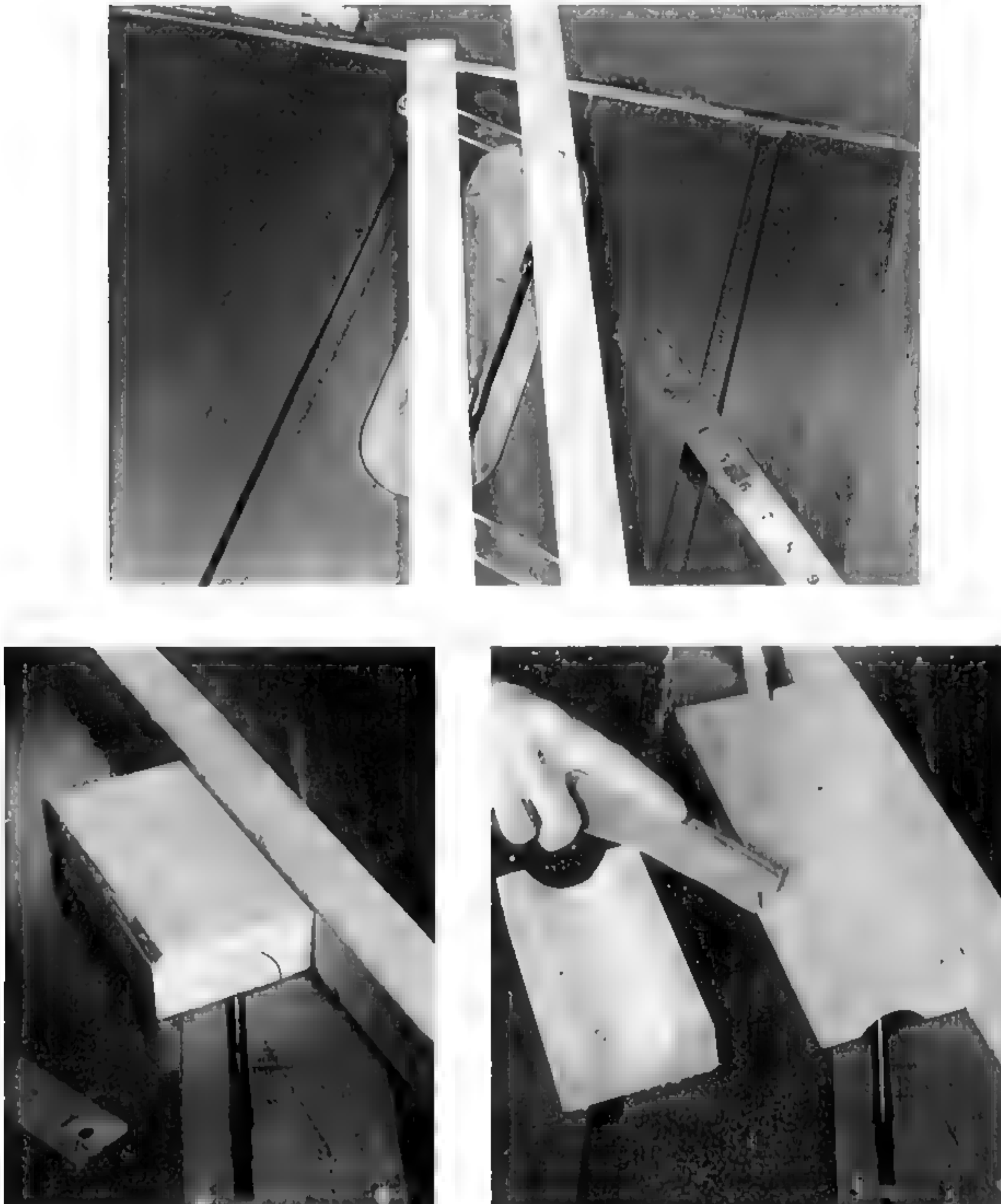


Figure 2-21
Cove cutting. *Top:* Using parallel rule to determine angle. *Left:* Determining distance of fence from blade. *Right:* Cutting cove by raising blade 1/16 inch (1.59 millimeters) at a time.

workpiece is against the wood fence, the centerline of the workpiece will intersect the centerline of the saw blade (Fig. 2-21). A number of light cuts are made, starting with the blade adjusted ¹⁄₁₆ inch (1.59 millimeters) above the table. After each pass, the blade is raised ¹⁄₁₆ inch (1.59 millimeters). The corebox used as an example (2-inch diameter) would require 16 passes over the blade for both corebox halves.

8. Close one end by sanding a 2 degree draft on both pieces and attaching pieces with equal draft cut on one side (Fig. 2-22).
9. Install core vents if the box is to be used with a core blower *or* if it is gassed to harden the core (as is the case with sodium silicate/CO_2 cores).

NOTE: This corebox is held together with a C clamp and filled and packed through the hole at the top end (Fig. 2-23).

Figure 2-22
Two degrees of draft are sanded on the lower end of the corebox and this end is closed with pieces that have 2-degree draft on the edges that are attached to the corebox.

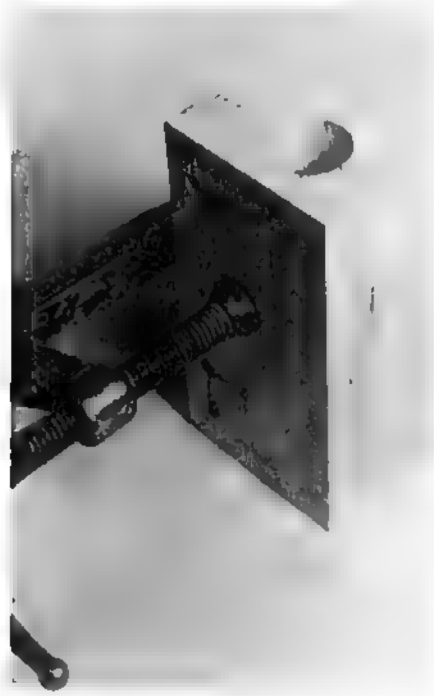


Figure 2-23
Corebox ready for use.

Complicated Coreboxes

Coreboxes of complicated shapes are seldom carved out of solid wood. Traditionally they were produced as fabricated wood assemblies. Today, many are produced by making a **core stick,** or plug the exact size and shape of the core, and pouring plastic around it in such a way as to achieve a cavity of the desired shape.

Fabricated Wood Assembly: Complicated coreboxes are divided into sections that permit the geometric shapes in that section to be fabricated easily. The individual sections have common length and width dimensions with the thickness of various sections matching the divisions determined earlier. The proper shape is machined into each section and then all sections are assembled (Fig. 2-24). Since centerlines are eliminated during fabrication, offset control lines are drawn on the parting surface about 0.5 inch (12.7 millimeters) in from both ends of each section. These lines ensure proper centering of the sections during assembly. The sides of the assembled corebox are then trimmed, if necessary, and reinforced with extra pieces of wood. To ensure registration, complete one corebox half, then assemble the other in contact with it.

Poured Plastic Coreboxes: Several plastics are available to the patternmaker. These can be very valuable in producing complicated pattern or corebox shapes. If the plastic is carefully selected to resist any attack

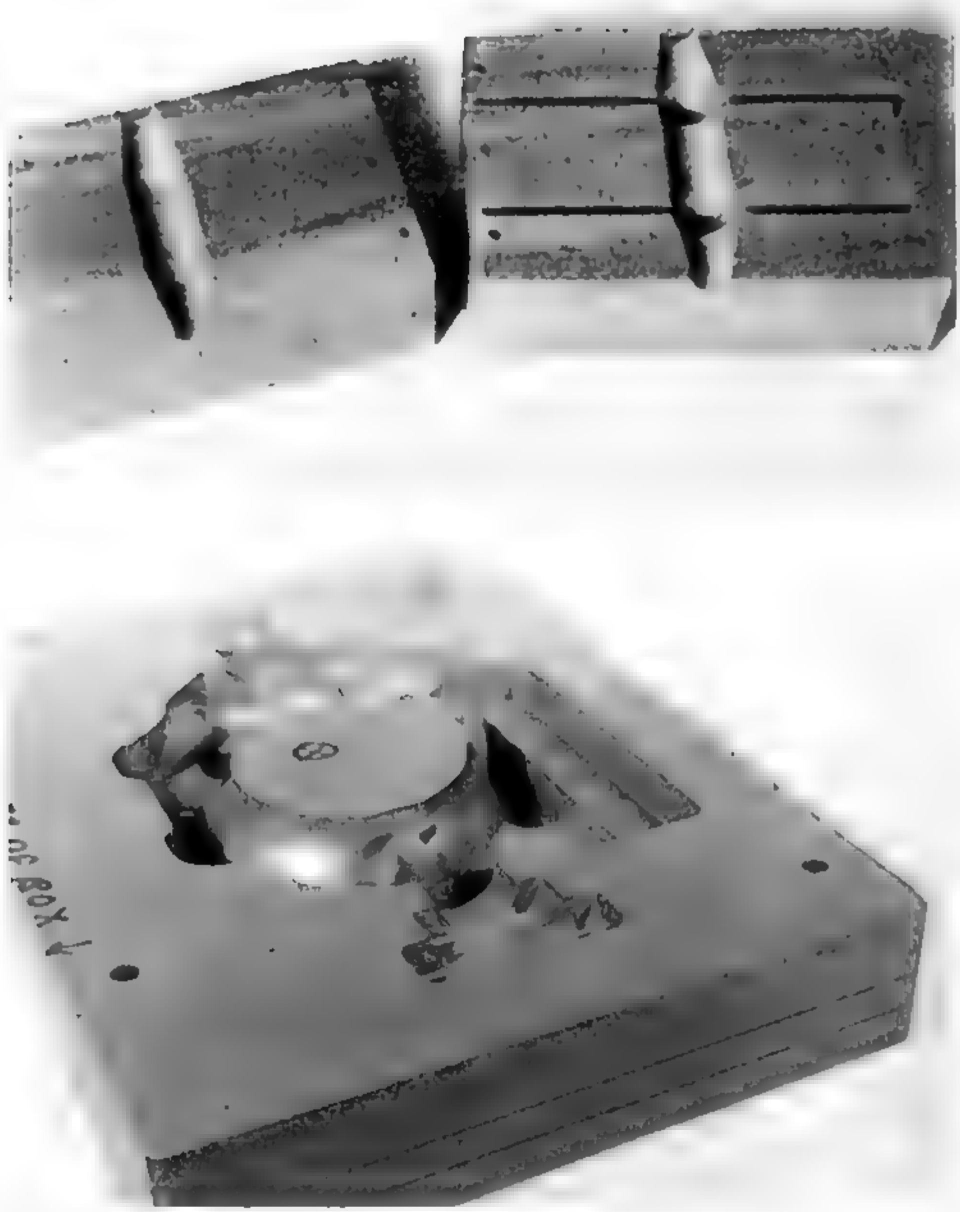


Figure 2-24
Top: Simple corebox showing how three separate pieces are fabricated *and then* assembled. *Bottom:* A more complicated corebox using the same principle. The bottom board is flat and serves as the bottom of the corebox. The center and top boards, however, were each cut to the specified shape prior to assembly. Fillets and pattern paint applied after assembly might lead the casual observer to think that the internal shape was carved out of a solid piece of wood.

or softening by the binder in the core process that is to be used, the resultant tooling is durable with excellent detail and dimensional stability. To produce a complicated internal shape in a plastic corebox:

1. Fabricate a core stick or **core plug.** This should be an exact duplicate of the core that is required.
2. Fabricate or devise a means to support the core stick at its parting line and to provide a smooth parting surface. In the preparation of the core box illustrated in Figures 2-25 and 2-26, half of the core stick *without* dowels was laid flat on a piece of glass.
3. Surround this assembly with a temporary wooden flask. In the illustrated corebox, a wooden block with the center portion removed by band sawing was used.
4. Coat the core stick, parting surface, and inside surfaces of the wooden flask with a mold release compatible with the plastic being used.
5. Mix plastic according to the directions provided and fill the flask (or block).

Figure 2-25
The half of the core stick *without dowels* is still in the cavity produced by pouring a plastic material (white) over it and allowing the plastic to set. Holes have been drilled for aligning the other half of the corebox.

Figure 2-26
The top half of the core stick has been positioned on its mate. The band-sawed (white) block has been set in place on aligning dowels. All is ready for applying the mold release and pouring the plastic.

NOTE: To cut down on the volume of the relatively expensive plastic material, less expensive materials, such as wood, are often used to take up some of the space.

6. Allow the plastic to set.
7. Machine two locating dimples at appropriate places, or drill holes for dowels (Fig. 2-25).
8. Place the top half of the core stick on its mate.
9. Surround the corebox half with the temporary wooden flask or set the band-sawed block in place on aligning dowels (Fig. 2-26).
10. Coat the core stick, parting surface, and inside surfaces of the temporary wooden flask with mold release.
11. Mix and pour the other half of the corebox. Allow plastic to set.
12. Machine the outside edges as necessary and install vents, if needed.

Sprayed Metal Tooling: The spraying of metal particles at high temperatures with oxyacetylene equipment has been used for a number of

years to *build up* and *repair* machine parts. However, two recently developed pieces of equipment produce cool metal particles that are sprayed to produce foundry tooling.

In one method, alloys of tin and zinc or tin and bismuth are melted in an electrically heated gun and atomized with compressed air. The other system causes the ends of two electrically isolated similar or dissimilar wires (1/16-inch [1.58 millimeters] diameter) to come into contact, producing an electric arc. The molten metal that results from the electric arc is carried to the object with a stream of compressed air as a cool, forceful spray that forms a dense, well-bonded coating. This system is so sensitive that it can spray a coating of molten zinc on a fresh apple without scorching its skin. On the other hand, it is such a rugged system that it can perform on a continuous basis in spraying nickel, stainless steel, bronze, copper, aluminum, zinc, and babbitt.

Any patternmaking material, including pasteline (clay), can be sprayed. However, the surface must be smooth and covered with two coats of polyvinyl alcohol mold release. A shell thickness of 0.060–0.080 inch (1.52–2.03 millimeters) is sprayed over the *negative* pattern or model. Deposition rates vary but such a shell with a surface of approximately 1 square foot (92,903 square millimeters) could be sprayed in 10–15 minutes. The shell is stripped from the negative model, which can be recoated with mold release and resprayed if duplicate tooling is required. The shell is surrounded with a temporary wooden flask (coated with mold release), and an epoxy resin with aluminum granules is cast in place against the back of the shell. After 12–16 hours, the resultant tooling can be put in service. The surface of the sprayed metal will reproduce exactly the quality of the surface it was sprayed against. The epoxy/aluminum granule reinforcement provides good dimensional stability and thread-holding capacity if tapped holes are required for mounting. Tooling produced in this manner does not have the wear resistance of cast iron but it is suitable for low- to medium-length production runs.

TEST YOUR KNOWLEDGE

1. Loose patterns, matchplates, coreboxes, etc., all fit into the category of __________ __________.
2. Although certain conditions might dictate larger or smaller angles, a common draft angle is a __________ degree angle.
3. Patterns are made oversize to allow for __________ and __________.
4. Pattern shop lumber must be properly cured and __________.

T-F 5. Brass dowels are used for the temporary positioning of separate foundry tooling parts, but wooden dowels can be used for *either* temporary *or* permanent positioning of such parts.

6. Fillets are used in inside corners on a pattern to avoid shrinkage cracks in the corner of the ________.

7. The fillet material most used by today's patternmakers is ________ ________.

T-F 8. Fillet sizes are based on the radius of the fillet in $\frac{1}{32}$-inch increments.

9. Super-strength plasters used by patternmakers are known as ________ ________.

10. Using hot water when mixing plaster will ________ the process.

T-F 11. Some aluminum foundry tooling is made more durable by coating the surface with a harder metal.

12. The metallic coating that best meets the needs of the foundry tooling is ________ nickel.

T-F 13. A knife is sometimes used to make layout lines for wood patterns.

14. Sometimes the only way a pattern can be drawn cleanly from the sand is to provide the pattern with removable parts called ________ ________.

15. An unmounted pattern is called a ________ pattern.

T-F 16. Most industrial castings made in green sand are produced in molds formed by some kind of a matchplate.

17. The plate material for matchplates to be used in a school foundry should be at least ________ thick.

T-F 18. Mounting the pattern, sprue base, and runner and gates on a plate should be done after the plate is fitted to the flask.

T-F 19. For perfect alignment of pattern halves on a plate, it is important that the holes in the plate be slightly larger than the press-fit dowels.

20. Coreboxes to be filled with a core blower must have ________ to allow the air in the box to escape.

CHAPTER 3

Coremaking

Representative Core Processes • Making Cores • Core Sand Mixtures Used for Making Molds

CHAPTER GOALS

After studying this chapter, you should be able to:

1. Explain the difference between green sand and dry sand cores.
2. Name an industrial coremaking process that does not lend itself to being carried out in the school foundry and explain why this is so.
3. State the three categories of coremaking materials.
4. Explain why metal coreboxes are required for making shell cores but are not required for making oil-sand cores.
5. Compare no-bake and cold-box coremaking in regard to equipment required, sand mixture, coreboxes used, and speed of cure.
6. Explain the circumstances that result in a core blow.
7. Point out some of the advantages of using chemically bonded sand (instead of green sand) in moldmaking.

TERMS TO KNOW (see Glossary)

Green sand core	Sodium silicate/CO_2 core	Cold box core
Dry sand core	Hot box core	Investment time
Oil-sand core	No-bake core	Cure time
Shell core	Catalyst	Cold flour paste
Vapor-cured core	Strip time	Hot melt adhesives
Heat-cured core	Continuous mixers	Creep

The outside shape of a casting is determined by the pattern. Internal openings or cavities in a casting are produced by one or more sand cores. If the sand cores are produced as a part of the mold that is made when the pattern is rammed up, they are known as **green sand cores.** More often, however, when a core is spoken of, the reference is to sand that has been mixed with special binders, shaped, and then processed to retain its shape. The resultant **dry sand core** is placed into specially designed locations in the mold cavity (core prints) before the mold is closed and poured. The core prevents metal from entering those portions of the cavity from which it should be excluded. The heat of the molten metal destroys the bonding material of the core sand mixture so that after the casting has solidified and is shaken out, the core sand falls away, leaving the desired opening in the casting.

Cores are made *ahead of time* so they will be available for placing in molds *prior to closing.* The desired shape of a dry sand core is provided by a tool called a corebox. The processes by which the sand is forced to retain its shape vary, depending on the ingredients used to make the core sand mixture and on subsequent processing.

Before 1943, coremaking was simple. There was one core process, known as **oil-sand,** which had been used for hundreds of years (and is still used today). In 1943, Johannes Karl A. Croning developed the **shell core** process. Since then, there has been a dramatic increase in coremaking technology. At present there are at least 21 different coremaking systems. Over 160 proprietary materials from about 10 manufacturers are available for making cores. All these materials (Fig. 3-1) can be categorized as **vapor-cured** (cured by a gas of some kind), **heat-cured** (cured by heat), or **no-bake** (cured by chemical reaction).

Not all industrial coremaking processes lend themselves to use in the school foundry. Some processes require sophisticated equipment, and some involve toxic materials. However, you should understand the place of cores in the metalcasting process, know something of the variety of coremaking processes that exist, and make and use some cores.

	Different Proprietary Materials Available	Representative Manufacturer	Trade Name
Vapor-cured Systems			
Phenolic urethane—amine	[illegible]	Ashland	Isocure
Phenolic ester	1	Borden	Beta set
Furan/peroxide—acid cured	1	Uni-West	Uni-Cure
Sodium silicate/CO_2	9	Interstate	Insil
Free radial cured	1	Ashland	Isoset
Epoxy—SO_2	1	Ashland	Core Lube
Heat-cured Systems			
Shell (hot coat)	2	Acme Resin	Plasti-flake
Shell (cold coat)	3	United Erie	Unikote
Hot box (furan)	8	Ashland	Chem-Rez 100 Series
Hot box (phenolic)	12	Kordell	Thermo 745
Hot box (modified mix)	4	Southern Fdry Resin	Chem Cast HB 125
Warm box (furan)	5	Thiem	Fas Set 90
Core oil	16	Thiem	QB-57
Phenolic baking binder	[illegible]	Delta Resins	Phen Core Oil 10-69
Urea formaldehyde baking binder	5	Borden	Thor FB-22
No-bake Systems			
High nitrogen (6% or more) furan—acid cured	[illegible]	Reichhold Chemicals	Fondaez
Medium nitrogen furan—acid cured	12	Acme Resin	Super Set
Low nitrogen (3% or less) furan—acid cured	20	Kordell	Jet Set 16
Phenolics—acid cured	17	C-E Cast	Kold Kure
Alkyd oil urethane	15	Ashland	Linocure
Phenolic urethane	6	Ashland	Pep Set
Sodium silicate—ester cured	10	American Colloid	Accoset
Phosphate—oxide cured	1	Ashland	Inoset
Phenolic ester	2	Borden	Alpha-Set

Figure 3-1
Coremaking systems and proprietary materials available.

REPRESENTATIVE CORE PROCESSES

Oil-Sand

Oil-sand cores (the *basic* cores prior to 1943) fit into the category of heat-cured cores. Natural oils (such as linseed) or synthetic resins are mixed

with sand, cereal, and water. Small amounts of clay and other additives are sometimes used to achieve certain specific characteristics.

Oil-sand cores *can* be made in the school foundry. Mixing equipment need not be elaborate. An electric or natural gas oven can be used for baking.

Oil-Sand Preparation: The ingredients and procedure for making a general-purpose oil-sand core mixture are given below. If a small muller is not available, the following 10-pound batch can be mixed by hand:

Percentage by weight	Weight	Ingredient
97.5	9 pounds, 12 ounces (4.4 kilograms)	Sand
1.0	1.6 ounces (45 grams)	Cereal
1.5	2.4 ounces (68 grams)	Core oil
3.0	4.8 ounces (136 grams)	Water

1. Weigh all ingredients.
2. Mix sand and dry ingredients for 2 minutes.
3. Add water and mix for 2 minutes.
4. Add oil and continue to mix for 3 minutes.
5. Store in airtight container or cover with wet burlap until ready to use.

NOTE: Larger batches can be mixed using percentages given.

Making Oil-Sand Cores:

1. Clean corebox as necessary.
2. Fill and ram sand in corebox.
3. Strike off surplus sand.
4. Cover box with metal plate.
5. Turn over.
6. Vibrate or rap box.
7. Lift box off.
8. Place in oven carefully.

NOTE: If core will not hold its shape prior to baking, increase water slightly.

Baking Oil-Sand Cores:

1. Set oven to 400–425F (205–230C).
2. Bake 1 hour per cross-sectional inch.

NOTE: If core is too weak after baking, increase oil slightly. If core has poor collapsibility (does not lose its strength after being surrounded by the metal in the casting), decrease oil slightly.

Shell

Shell cores fit into the category of heat-cured cores. The heart of the process is that each sand grain is coated with a plastic resin. In the presence of heat, the resin liquifies momentarily and then cures to a hard mass, thus bonding adjacent grains together. Therefore, when a hot-metal corebox is filled with dry shell sand, the heat starts to affect the resin and sand grains at the hot corebox wall and moves progressively toward the center. When a shell thickness of about ⅛–3⁄16 inch (3–5 millimeters) has developed, the corebox is inverted and the cool unaffected sand in the center is poured out. The shell core remains in the hot corebox through a cure cycle (of about 1 minute) after which it is quite durable. It can be removed and handled readily. Except for removal of parting lines and cooling, the core is ready to use. Obviously, *solid* cores can be made with this sand by merely failing to empty the box.

Although shell cores commonly are made on machines (Fig. 3-2), they *can* be made in the school foundry with minimal equipment. Coated shell sand and metal coreboxes are required.

Making Shell Cores: The following procedure should be followed in making shell cores *with minimal equipment.*

1. Spray cavity of corebox with silicone mold release.
2. Assemble corebox and hold with C clamp.
3. Place corebox in gas or electric oven.
4. Heat until box is up to 400–500F (205–260C).
5. Using heat-protective gloves, remove corebox from oven.
6. Fill with shell sand.
7. Watch as sand near cavity wall changes color, indicating thickness of the shell being formed.
8. When a shell of ⅛–3⁄16 inch (3–5 millimeters) has developed, invert corebox to discharge loose sand.

Figure 3-2
Shell core ready to be removed from hot corebox of shell core machine.

9. Replace corebox in oven for about 1 minute to cure.
10. Remove corebox from oven, open, and remove core.
11. Remove any flash or parting lines with a file and set aside to cool.

Sodium Silicate/CO_2

Sodium silicate/CO_2 cores (often called CO_2 cores) fit into the category of vapor-cured cores. The process consists of coating sand grains with a sodium silicate binder. This mixture is packed into a corebox, rapped or vibrated, and then gassed with carbon dioxide for a short time (about 10 seconds). This hardens the core, allowing it to be removed from the corebox. The core can be used immediately.

CAUTION: Overgassing results in cores that crumble easily.

This process provides a number of advantages:

- Good dimensional accuracy
- Smooth finish
- Rapid production
- Less gas evolved in use than with many other core-sand binders
- No baking ovens required
- No smoke or odor

Major disadvantages, at first, were poor collapsibility and the tendency for cores to absorb moisture, which shortened shelf life. Efforts to solve these problems have been quite successful, and the CO_2 process is used to make many cores.

This process is *very well-suited* to use in the school foundry. The cost of the CO_2 gassing equipment is the main expense. The binder can be purchased from some school shop suppliers or obtained through the good graces of a nearby foundry. A small muller is highly desirable, but not essential. Small batches of core sand can be mixed by hand or with a stirring device mounted in a drill press. If kept in an *airtight* plastic bag or container, the sand mixture remains in a usable condition for a number of weeks. The integrity of the container is critical, however, for CO_2 present in the air causes the mixture to harden. In the absence of gassing equipment, a sodium silicate sand mix can be rammed into a corebox, rapped, left to harden in the box (this can be hastened with heat), and then removed and used. Although this procedure would not accurately reproduce the process, a usable core would result.

NOTE: Since CO_2 in the air causes the mixture to harden, it is important that mixing equipment be cleaned shortly after use. Failure to do this will result in the buildup of a rock-hard deposit. Such deposits on mixing equipment, coreboxes, and so on, can be removed by soaking in water. A wood corebox should be wiped repeatedly with a damp cloth or sponge rather than immersed in water, which could damage the corebox.

Recent developments in sodium silicate core technology have resulted in substituting either liquid or powder catalysts for the CO_2 gas. In so doing, much of the speed of the process has been sacrificed. However, this development makes it easy to use the process in school foundries if binders and catalysts are available.

Preparing Sodium Silicate/CO_2 Core Sand:

1. Clean muller of all loose sand.
2. Weight clean, clay-free sand (Fig. 3-3) and add to muller.
3. Weigh out binder (2–5 percent by weight) (Fig. 3-4).

NOTE: The correct amount of binder for the specific kind and grain size of sand being used must be determined.

4. Start muller; add binder 1 inch (25 millimeters) from edge of muller, pouring in a steady stream so that all binder has been added in about 10 seconds (Fig. 3-5).
5. Mull for 4 minutes. Be sure binder is not deposited on side walls instead of being mixed with sand.

Figure 3-3
When preparing core sand, weigh sand carefully.

Figure 3-4
The specified amount of binder should be weighed with care.

Figure 3-5
Add binder to sand (in muller) in a steady stream.

NOTE: Use a special tool to scrape buildup from sides of muller during this time (*do not use fingers*).

6. Open muller door and empty into *airtight* container.
7. Clean muller, especially behind plows.

Making Sodium Silicate/CO_2 Cores:

1. Clean corebox as necessary.
2. Dust with parting compound.
3. Fill to overflowing with CO_2 sand (Fig. 3-6).
4. Ram sand tightly into corebox (Fig. 3-7).
5. Strike off excess sand (Fig. 3-8).
6. Rap corebox or use vibrator to loosen sand in box (Fig. 3-9).

NOTE: It is *very important* that rapping or vibrating be done *before* gassing.

Figure 3-6
Corebox is filled to overflowing.

Figure 3-7
Core sand is tucked into corners with fingers and then rammed tightly.

Figure 3-8
When the corebox is rammed completely full, the sand storage can should be closed and the excess sand struck off.

Figure 3-9
It is *very important* that the corebox be rapped or vibrated at this time (before gassing).

7. Place cover on corebox.
8. Gas with CO_2—approximately 5 pounds of pressure for 10 seconds will work for most small cores (Fig. 3-10).

NOTE: Specific gassing pressures and times can best be determined by experimentation. Enough CO_2 must permeate the core to harden it. Too much CO_2 will cause the core to crumble easily.

9. Turn off CO_2 regulator *and* cylinder valve.
10. Remove cover from corebox.
11. Remove pouring basin from corebox (Fig. 3-11).

Hot Box

Hot box cores fit into the category of heat-cured cores. The hot box coremaking process, developed in 1958, is similar in a number of respects to the shell process developed earlier. Both processes involve heated coreboxes and synthetic resin-coated sand that hardens in the presence of heat. The chief difference between the two is that the hot box sand mix is wet and permits conventional core blowers to be used to fill and pack

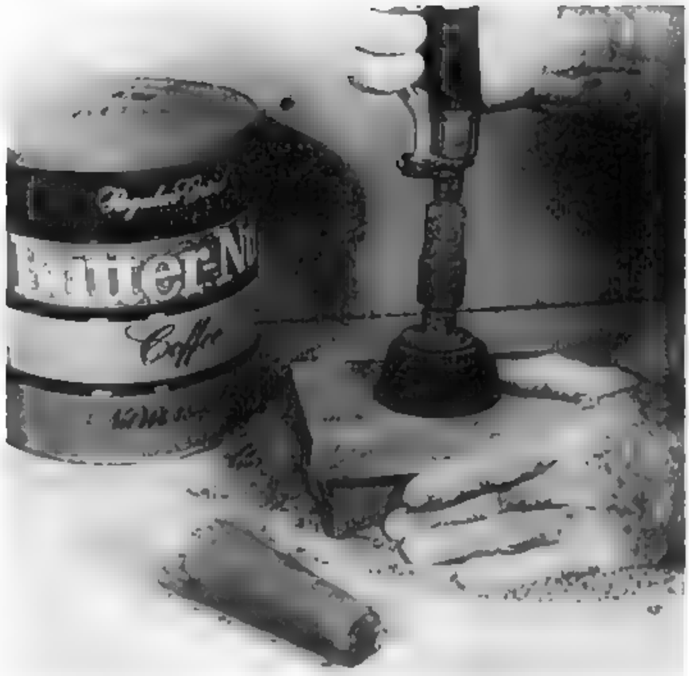


Figure 3-10
With gassing cover on corebox, gas with CO_2 at appropriate pressure for proper length of time.

Figure 3-11
The core (in this case a pouring basin made of core sand) can be stripped from the corebox immediately after gassing and put to use.

the coreboxes quickly. Hot box cores can be made faster than shell cores, but much more material is used in the hot box process because the core is solid.

This is an industrial coremaking process that is *not* easily adaptable to the school foundry. However, if a small muller, a metal corebox, and an oven are available and the needed resin and acid catalyst can be secured, a simple version of the process can be carried out. Mixed sand added to a metal corebox heated to 400F (205C) or higher can be removed in 10–20 seconds. The exterior will be hard. Heat transfer and the exothermic (heat-producing) nature of the curing action cause the uncured sand in the center of the core to harden within several minutes, producing a typically solid hot box core. Some odor is associated with the process, some care is required when working with the acid catalyst, and the bench life of the mixed sand is limited to ½ to 1 hour.

No-Bake

No-bake cores fit into the category of cores that are cured by chemical reaction. All such processes involve a binder and a **catalyst.** The absence of heat (except for the small amount generated by the chemical reaction) eliminates the need for expensive heated coreboxes or ovens. Unpleasant odors are minimal. Some individuals are allergic to the liquid ingredients and even to the mixed sand, but protective gloves usually solve this problem. Within limits, the proportions of the liquid ingredients can be varied to achieve different **strip times.** The temperature of the sand also affects strip time. The bench life of the mixed sand is short—it must be used immediately after mixing. **Continuous mixers** are used in an industrial setting, and the proportion of liquid materials and the temperature of the sand are controlled to produce satisfactory cores as fast as possible, within the limitations of the equipment being used.

This is a process that *can* be adapted to the school foundry. Small batches of sand can be mixed in a heavy-duty household mixer. The main problem is to secure the necessary binder and catalyst. These materials may be available through the courtesy of a local foundry. Wherever you get the materials, be sure to get mixing instructions, and then be sure to follow them.

NOTE: Be especially careful to avoid mixing the raw resin and catalyst together, since doing so may produce a violent reaction.

Experiment rather cautiously until you have determined the characteristics of the no-bake sand mix you are using and know what precautions must be taken to ensure safety of personnel, preservation of coreboxes, and clean-up of equipment.

No-Bake Core Sand Preparation:

1. Weigh sand, binder, and catalyst precisely.
2. Spray mixing bowl with vegetable oil pan coating (such as Pam®).
3. Mix sand and catalyst.
4. Add binder and mix.
5. Use sand immediately—the bench life is very short, depending on amount of catalyst used.
6. Clean mixing bowl and equipment.

Making No-Bake Cores:

1. Spray cavity of corebox with vegetable oil pan coating.
2. Place core sand in box as soon as possible after it is mixed.

NOTE: Do *not ram*—just pat (or jolt) the sand in place.

3. Strike off excess sand.
4. Set corebox aside until the core is strong enough to strip from the box.

NOTE: This could be from 2–10 minutes depending on the binder system used. Varying the amount of catalyst can change strip times also. Some no-bake binders change color as they cure. For example, the newly mixed color, light green, may change to a darker green as curing takes place. Such a feature can be very useful in helping an inexperienced no-bake coremaker decide when to strip the core from the box.

The no-bake process provides an excellent opportunity for you to become involved in some meaningful experiments. The careful variation in amounts of catalyst to achieve the optimum strip time is a realistic challenge that will give you some idea of the interesting problems with which industry is concerned on an ongoing basis.

Cold Box

Some **cold box cores** fit into the no-bake category, but those most commonly used in industry fit into the category of vapor-cured cores. The search for a cold core process resulted in the (ungassed) cold box process (somewhat reminiscent of no-bake) developed in 1964. Four years later

the (gassed) cold box process (which is rather similar to sodium silicate/CO_2) was developed. This process uses a two-part binder system (or, more recently, a one-part binder system) and a catalytic gas. It has attracted much attention and is widely used in the industry.

This process *does not* lend itself to the school foundry. The gases that are used either are highly flammable (TEA and DEMA) or have a pungent odor (SO_2) that most personnel find very irritating. Gassing must be done in a sealed chamber from which the gas can be collected and sent through a scrubber before being released to the atmosphere.

All aspects of the process must be carefully controlled. The sand temperature must be 50–85F (10–30C). The moisture content of the sand must not exceed 0.1 percent. One of the binders must be protected from coming into contact with water lest it become a thick, sticky mass impossible to use. Conventional wheel-type mixers can be used, but a better mixture will result from removing the wheels and allowing the plows to do the mixing. The bench life of mixed sand is a maximum of one hour. Because the gas used (either TEA or DEMA) is highly flammable, gassing pressures must be closely controlled and the air that carries the gas catalyst must be completely dry and preferably 100–150F (37–65C). Only certain release agents should be used on coreboxes.

The level of process control required might make you wonder if the advantages of the process equal all the problems of carrying it out. The speed of the process makes it all worthwhile. Twenty-second cycle times are common for cores of up to 3 pounds.

MAKING CORES

Most of the sand cores used in industry are made on a machine, but some, particularly oil-sand and sodium silicate/CO_2 cores, occasionally are made by hand.

Manual Coremaking

When sand cores are made by hand, the coremaker fills the corebox cavity with handfuls of sand and uses some kind of a ramming device to pack the sand tightly. The corebox is rapped or vibrated to loosen the sand. If the core is an oil-sand core, it is released carefully onto a flat plate or a specially shaped core dryer. When a sufficient number of such cores have been produced, they are moved to the oven for baking. If the process is sodium silicate/CO_2, after the sand is loosened by rapping or vibrating it is gassed with CO_2 and then stripped from the corebox. It may then be stored, coated with core wash and oven dried, or go directly to the molding line and be placed in a mold.

Coremaking Machines

A number of machines have been developed to speed coremaking. These are available in a wide variety of sizes and shapes and are based on a variety of operating principles. Several machines are described below.

Core Blowers: The **core blower,** the first coremaking machine to be developed, is still commonly used. It uses compressed air to fill and pack sand into coreboxes. It is important that the coreboxes have vents so that air in the box can escape as the sand enters. Sand must have good flowability characteristics. Millions of tons of sand have passed through core blowers in the rapid production of small- to medium-sized cores.

Shell Core Machines: Most shell cores are produced on machines in which the corebox is clamped to heated platens *above* a sand hopper (Fig. 3-12). The corebox is heated to at least 450F (232C). When the cage is rolled 180 degrees, the sand hopper is positioned *above* the corebox where sand is gravity-fed into the corebox. The blow valve is pressed to ensure complete filling of the corebox. After an **investment time** of 5–10 seconds, the cage is rolled back to its original position. Sand in the center of the core, which was not affected by the heat, flows back into the sand

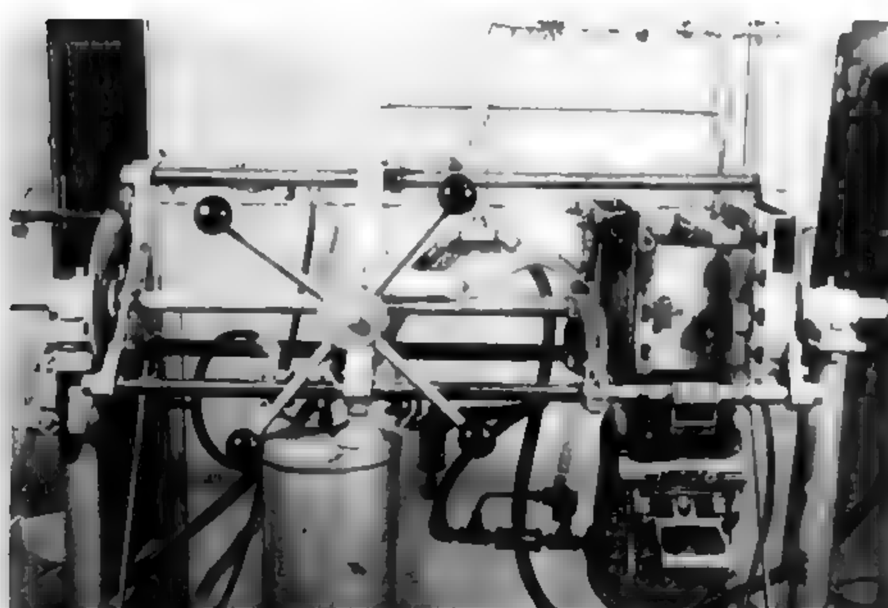


Figure 3-12
A small shell core machine appropriate for use in a school foundry.

hopper. After the hollow shell of sand has cured 15–30 seconds (**cure time**), the corebox is opened and the core removed.

Cold Box Machines: Equipment for making cold box cores is available in many different sizes and designs. All, however, would have the following components: sand hopper, blower, corebox, gassing manifold, purging air, and scrubber (Fig. 3-13).

Continuous Mixers: All coremaking processes involve mixed sand. In no-bake coremaking, however, where the mixed sand *must be used immediately,* a continuous mixer is the *primary* machine. Coreboxes, a conveyer system, and rollover and stripping devices are required to make the process efficient, but the continuous mixer is of most importance. It must meter raw materials accurately, operate on either continuous or interrupted cycle, handle fast-setting binder systems, and produce thoroughly mixed, "fluffy" sand on a consistent basis (Fig. 3-14).

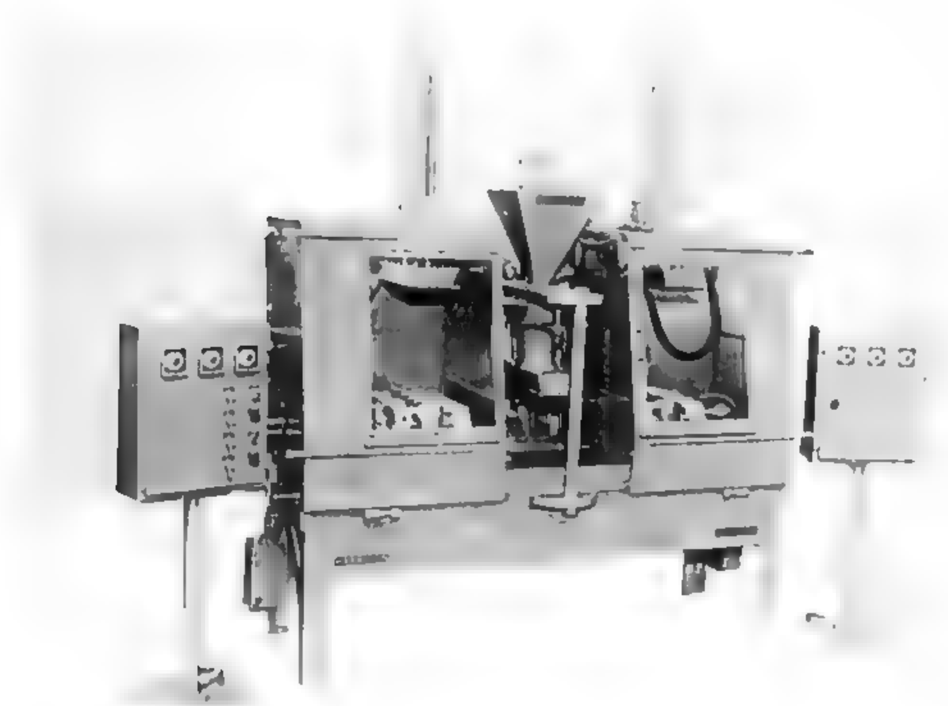


Figure 3-13
A small industrial model cold box coremaking machine that accommodates two coreboxes. Either can be moved to the central blowing (filling) station and then moved into a cabinet for gassing. After purging, the corebox and cabinet are opened and the core removed. This is one of the fastest ways of making cores with 20-second cycle times common for cores weighing up to 3 pounds.

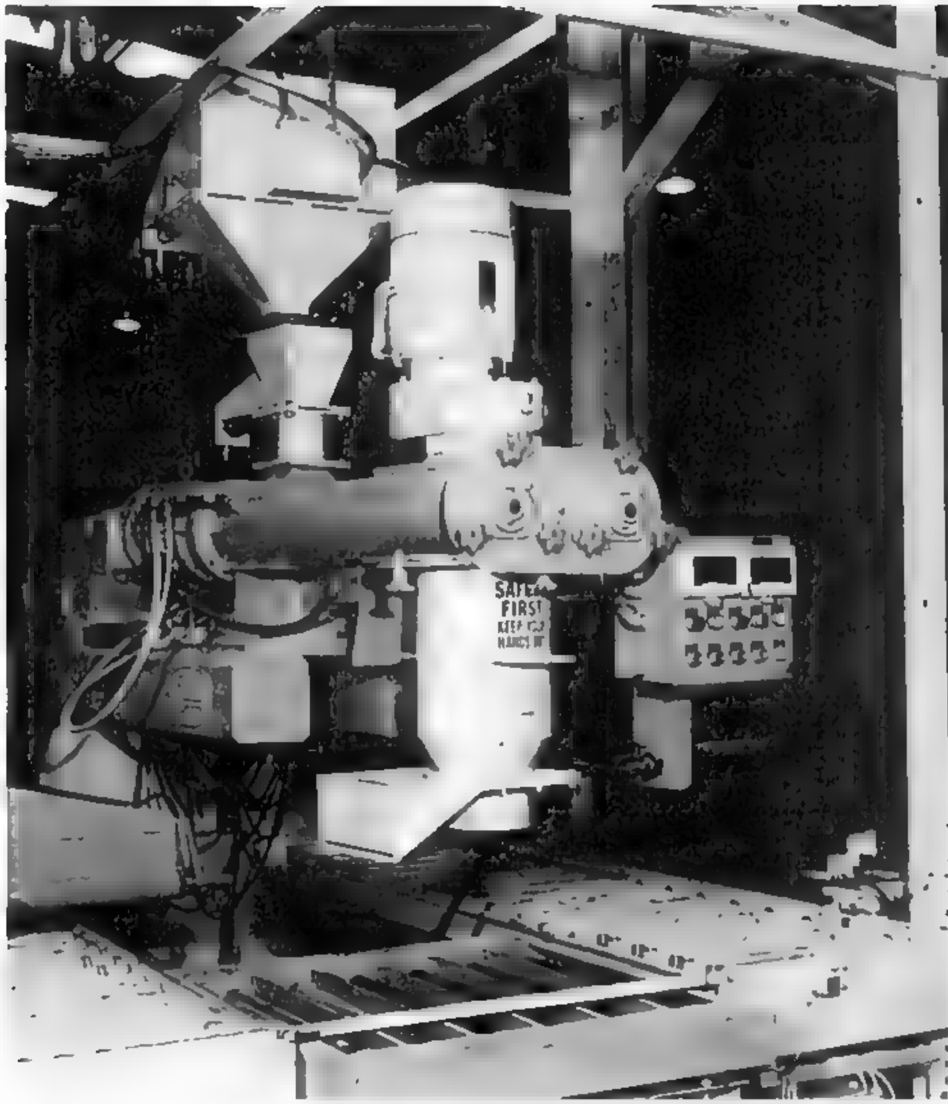


Figure 3-14
A continuous mixer for no-bake coremaking.

Core Venting

When molten metal is poured into green sand molds, certain gases are generated from the moisture and binders in the sand. These gases must be able to escape through the small open spaces between the firmly packed sand grains or through vents or flowoffs made by the molder. This problem of gas formation and the need for it to escape is increased when dry sand cores are placed in the mold. If gases formed by molten metal contacting the core cannot find a place to go *within* the core, of if they cannot

escape through the core and core prints of the mold, they will attempt to work their way through the molten metal itself. This usually results in a casting defect called a core blow (see Chapter 7). Shell cores, which are hollow, are normally trouble-free because gases formed have plenty of room to reside within the core. Solid cores are much more problematic. One solution is to use a coremaking sand with high permeability. However, if it is believed that core gases will be unable to remain in the core or be exhausted by the common technique of venting through core prints, some means of achieving open spaces within the core are devised. In cores that are made in halves and pasted together, the coremaker usually cuts some shallow vents in the surfaces before assembly. Oil-sand cores often are made with solid or hollow wax wires embedded in the core. When the core is baked, the wax melts, leaving a hole where gases can reside. Other materials or devices that are used to produce such internal openings are nylon tubing and perforated metal tubes.

Core Assembly

Cores are often made in pieces and assembled by gluing the pieces together. The adhesive most commonly used in industry until the early 1970s was a **cold flour paste.** Cores assembled with such core paste would require oven drying or a long drying period before use. Although some core pastes are still used, many present-day core assemblies are made with **hot melt adhesives.** These fast setting materials save time, lock parts together quickly without **creep,** and disintegrate during pouring without adversely affecting the casting. Hot melt adhesives come in cartridges about 1¾ inches (45 millimeters) in diameter by 2 inches (52 millimeters) in length. They are dispensed from special, electrically heated guns. They can be used on all types of cores.

Core assembly in the school foundry can be accomplished with white glue, but minimal amounts should be used since excessive glue can cause gas problems. Coat surfaces and press them together. Cores that have been assembled should have the moisture in the adherent dissipated by allowing the assembly to set for about 24 hours. This process can be hastened by placing in an oven at 150F (65C) for about an hour.

NOTE: If sodium silicate/CO_2 cores are being assembled with white glue, the glue should be applied with a minimum amount of brushing or spreading, so that the water in the glue does not cause erosion of the sand surface.

If many cores are to be assembled, check to see if a hot melt adhesive gun can be borrowed from the laboratory where woodworking is taught. The hot melt adhesive that will adhere wood will probably work on your cores.

Core Wash

Many different proprietary materials have been developed for coating the surface of cores. Such materials are known as core washes. Core washes are used to seal the surface of the core. This prevents metal penetration of the core and results in an improved surface finish on that part of the casting produced by the core. Core washes also tend to force core gases to be exhausted through core print vents. Core washes consist of refractory materials (such as carbon, graphite, zircon, and so on) and a binder (such as bentonite or dextrin) suspended in a water or alcohol solution. The wash must be compatible with the core process used. For example, usually a water-base core wash is used on a heat-cured core and an

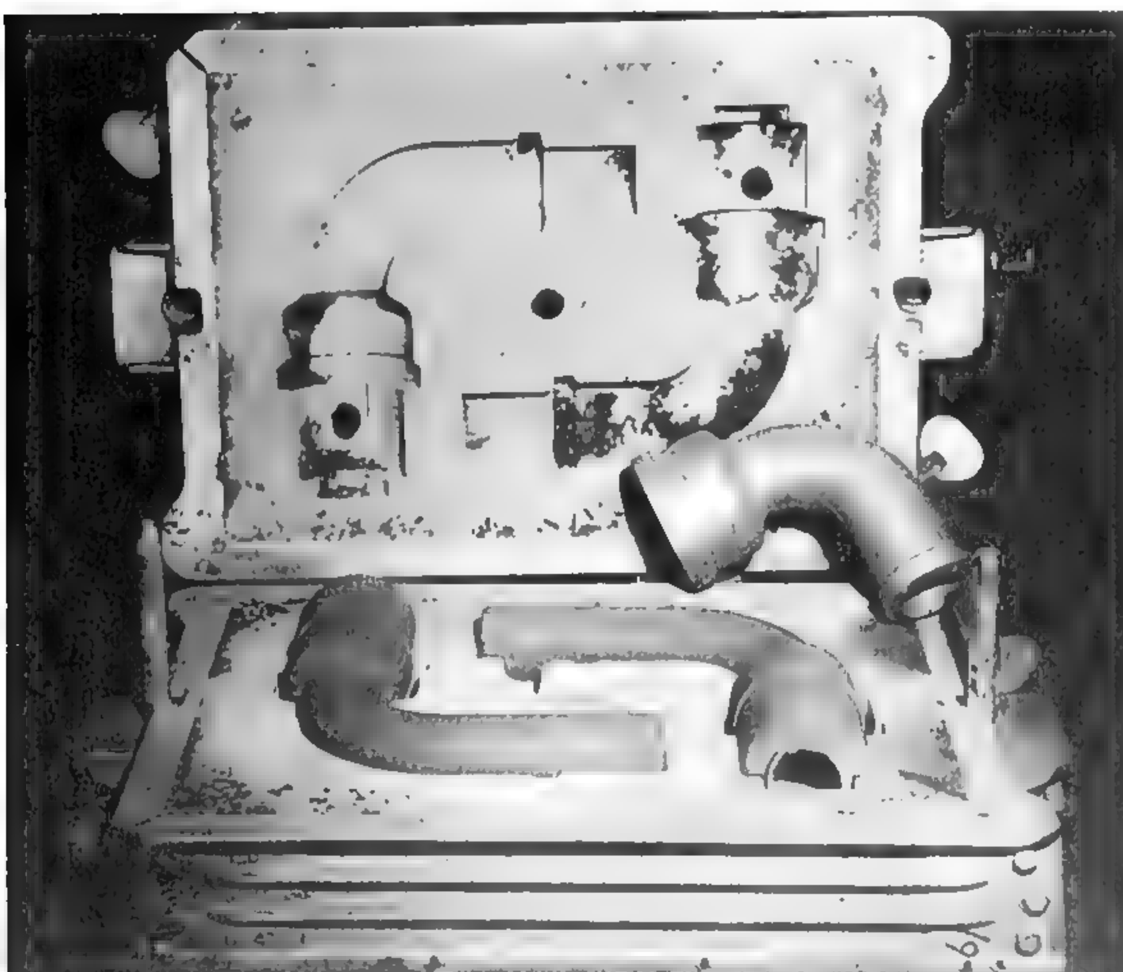


Figure 3-15
Core prints can be seen at each end of both mold cavities in the cope. Shell cores have been placed in the core prints in the drag. Also shown is a finished casting.

Figure 3-16
Chaplets of various shapes.

alcohol-base wash on self-setting cores. Core washes are applied by dipping, spraying, or brushing. After being coated with core wash, cores generally are sent through an oven to drive off all the moisture.

Core Setting

Cores are usually supported in the mold in one or more core prints (Fig. 3-15). Sometimes additional support is required to keep a core in position or help it retain its proper shape. Metal chaplets are commonly used to provide such support above and below a core. The common shape resembles a two-headed nail with large flat heads, but chaplets are made in a great variety of sizes and materials (Fig. 3-16). The material of the chaplet should be similar to or compatible with the metal, because *after* providing support for the core the chaplet is melted (or fused in place) by the molten metal and becomes a part of the casting.

CORE SAND MIXTURES USED FOR MAKING MOLDS

Some core sand mixtures and processes are easily adapted to making molds. You have learned how shell cores are made. In Chapter 8 you will see how the same material and some different tooling are used to produce shell molds. In like manner, the development of self-setting (and vapor-

cured) core sand has led to a substantial use of these sands for producing molds. The substitution of such sands for green sand occurs mostly in jobbing work and for medium- and large-size castings. The molds that result are strong and stable. They produce castings with surface finish and dimensional accuracy superior to green sand. Skilled molders are not required. Improved yield and reduced cleaning costs offset the relatively high cost of chemical binder. Also, the sand lends itself to reclamation and reuse. These factors help lower capital and labor costs, and therefore, chemical binder systems have replaced green sand in certain moldmaking situations.

Many molds are produced by discharging chemically bonded sand from a continuous mixer onto a matchplate surrounded by a flask. However, molding machines have been developed that blow and squeeze vapor-cured sand to produce vertical flaskless molds. Smaller sand systems, no flasks or flask-handling equipment, and reduced energy requirements are just some of the advantages over green sand molding that are claimed by the manufacturer.

It seems clear that no-bake and vapor-cured binders will see increasing use in the years ahead as substitutes for green sand molding. Even so, you should keep in mind that green sand molding continues to be the process responsible for the greatest tonnage of finished castings.

TEST YOUR KNOWLEDGE

1. Some internal shapes of castings are made with green sand cores but most cores are called __________ __________ cores.
2. A core should become __________ (stronger, weaker) after it is surrounded by molten metal.
3. Cores are made __________ (before, at the same time) the mold is made.

9. The heated metal coreboxes and synthetic resin-coated sand used in the shell core process are also used in making __________ __________ cores.

10. Shell cores are __________ (hollow, solid); hot box cores are __________.

11. No-bake cores are cured by __________ reaction.

T-F 12. No-bake sand has a very short bench life.

13. The most important machine used in no-bake coremaking is a __________ __________.

14. The type of core which is least problematic in regard to core blows is the __________ __________.

15. Adhesives used for assembling cores are core paste and __________ __________ glue.

16. The surface finish on the surface of the casting produced by a core can be improved by coating the core with __________ __________.

17. Heat-cured cores could be coated with __________ base core wash whereas self-setting cores would require an __________ base core wash.

CHAPTER 4

Gating Practice

Gating System Design • Gating System Requirements • Important Aspects of a Horizontal Gating System • Nine Simple Steps to a Calculated Gating System • Risering • Chills • Other Considerations and Reminders

CHAPTER GOALS

After studying this chapter you should be able to:

1. Indicate at least five factors involved in determining the size of the choke of a gating system.
2. Indicate at least three *requirements* a gating system should fulfill.
3. With a chart of diameters and areas of circles, and given the cross-sectional area of 0.3 square inches as the choke for an unpressurized gating system with a ratio of 1:4:4, determine the diameter of the sprue base, the CSA of a one-runner system, the appropriate width and thickness of the runners, and the depth of the sprue base.
4. Define a riser.
5. Indicate why side risers are generally preferred over top risers.
6. Describe the location of a hot riser as compared with that of a cold riser and indicate why hot risers are preferred.
7. Given the formula:

   $$\text{Diameter of riser neck} = 1.2 \times \text{neck length} + 0.1 \times \text{diameter of riser}$$

   calculate the diameter of a round riser neck for a 4-inch riser (assume a neck length of 1 inch).

TERMS TO KNOW (see Glossary)

Nomographs	Vents	Bulb
Horizontal gating system	Whisker vents	Open riser
Pouring basin	Flowoff	Blind riser
Tapered sprue	Liquid shrinkage	Dome
Sprue base	Solidification shrinkage	Neck
Runner	Solid shrinkage	Cold (dead) riser
Runner extension (sump)	Progressive solidification	Hot (live) riser
Gate	Directional solidification	Chill
Unpressurized gating system	Side riser	External chill
Choke	Top riser	Internal chill
Riser		

GATING SYSTEM DESIGN

A number of factors are involved in designing appropriate gating systems. In industry, the *pouring rate* in pounds per second (or kilograms per second) is determined from the *weight of the casting* and its *critical section thickness* (minimum thickness). The *fluidity of the metal* is determined from *metal compositional factors* and *pouring temperature.* The pouring rate is adjusted for 1) the fluidity of the metal and 2) the *friction coefficient* of the *gating system* (type of sprue, number of runners, gates, and so on). The *effective height of the sprue* is determined from the *height of the cope* and whether all the pattern is in the *drag* or in the cope, or whether *part* is in each. Knowing the *density of the metal* and the effective sprue height enables the *density/effective sprue height factor* to be determined. This factor, together with the *adjusted pouring rate,* is used to calculate the *cross-sectional area* (CSA) of the choke. The choke is the part of the gating system with the smallest cross section. It is the key to determining the size of most of the parts of a gating system. Once the choke has been determined, the design of the gating system can proceed.

Traditionally, these calculations have been made with formulae, charts, or **nomographs** (marked-off graphs on which a straight edge can be used to connect two known values to find a third unknown value). Computer programs are now available to help make the calculations, as well as to design the entire gating system.

A student in the school foundry *can* learn to *calculate* the CSA of the choke from pouring rate, metal fluidity, effective sprue height, and the like. It is enough, however, for most foundry students to design gating systems based on a recommended size of choke.

Much scrap is produced by poor gating practice. This is true in industry as well as in the school foundry. This chapter will provide a good foundation for the understanding of horizontal gating practice. It is suggested that those desiring a more detailed treatment of the topic use the American Foundrymen's Society books, *Basic Principles of Gating* and *Basic Principles of Risering.*

NOTE: All dimensions in this chapter are in inches or parts of an inch so you can focus on understanding the principles of gating without being distracted by unfamiliar metric measurements.

GATING SYSTEM REQUIREMENTS

It is obvious that some opening must be made in the mold for metal to run through to fill the cavity. When this need is satisfied, many novice metalcasters give the matter of gating no further thought.

However, providing a way to fill the cavity is only the *most obvious* of a well-designed gating system. Others are:

1. The metal should enter and fill the mold cavity quickly and quietly (as low in velocity and as free of turbulence as possible).
2. Provision should be made for keeping the first metal to flow through the gating system (which is inevitably damaged) from becoming a part of the casting. Only clean, undamaged metal should enter the mold cavity.
3. Metal should be distributed to the mold cavity so that proper directional solidification of the molten metal occurs.
4. The gating system should be economical. Systems should not use more metal than necessary (thereby reducing yield).

IMPORTANT ASPECTS OF A HORIZONTAL GATING SYSTEM

All these requirements can be achieved by incorporating the following important elements into a **horizontal gating system.** (There are vertical gating systems, but these are used so infrequently in school foundries that they will not be discussed here.)

1. *Pouring basin:* A **pouring basin** can be cut alongside the sprue, or a separate pouring basin made of core sand can be placed on top of the sprue. This will maintain a head (or reservoir) of molten metal above the sprue. The basin should be rectangular, flat-bottomed, and shaped (in cross section) as shown in Figure 4-1. It should be placed near the edge of the flask so the lip of the crucible almost touches it when pouring.
2. *Tapered sprue:* A **tapered sprue** can be cone-shaped and made with a cutter or square (better still, rectangular) and made with appropriately shaped wood pins. The CSA of the bottom of a sprue should be one third to one half the CSA of its top. This provides a choke, which fills the sprue as soon as possible, keeps it full, and ensures that the side walls of the sprue are under pressure. A good size for a round tapered sprue that is to be used in a school foundry is ½ inch in diameter (approximately 0.20 square inch CSA) at the bottom, ¾ inch in diameter (approximately 0.44 square inch CSA) at the top, and 7 inches long. Appropriate dimensions for a square tapered sprue

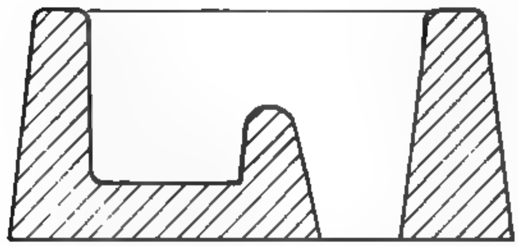


Figure 4-1
Cross-sectional view of a well-designed pouring basin that can be made of core sand and placed above the sprue. Such a shape can also be cut in the cope alongside the sprue.

are 7⁄16 inch × 7⁄16 inch at the bottom, 11⁄16 inch × 11⁄16 inch at the top, and 7 inches long. A rectangular tapered sprue might be ¼ inch × ⅞ inch at the bottom, ½ inch × ⅞ inch at the top, and 7 inches long. Other dimensions for a rectangular tapered sprue that would result in the bottom and top CSAs given above would work just as well. The sprue should be located close to the edge of the flask.

3. *Sprue base:* The **sprue base** should be 5 times the CSA of the bottom of the sprue. Its depth should be twice the depth of the runner. It should be flat-bottomed (Fig. 4-2) or slightly convex like a lavatory drain plug (Fig. 4-3), with corners slightly rounded.

4. *Runner shape:* The **runner(s)** should be wide and shallow (with dimensions such as 1.1 inches wide and 0.7 inch deep) and should decrease in CSA after each gate is passed.

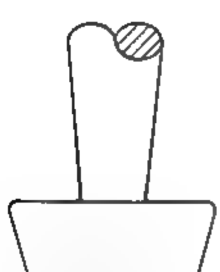


Figure 4-2
Common shape for a sprue base directly under tapered downsprue.

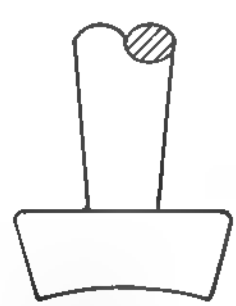


Figure 4-3
Modifying the lower surface of the sprue base to this configuration will further reduce turbulence.

5. *Runner location:* The runners should be in the drag, and the gates should be in the cope. This will ensure that the sprue and runner system is full before the gates start to flow.

6. *Runner extensions or sumps:* **Runner extensions** or **sumps** are the ends of the runners that extend beyond the last gates. They are used to prevent the first metal poured, which is inevitably damaged and cold, from entering the mold cavity.

7. *Gate shape:* The **gates** should be fairly flat and thin (but *never less than* the CSA of the choke) with the first gate at least 6 inches from the sprue.

8. *Unpressurized system:* The gating system should be **unpressurized.** This is achieved by having the CSA of the gates and runners greater than the CSA of the **choke** (often the bottom of the sprue) in the system. A common approach is based on a ratio of 1:4:4. With such a ratio, if the CSA of the choke is 1 square inch, the CSA of the runner(s) should equal 4 square inches and the CSA of all the gates (combined) should equal 4 square inches.

   The gating ratio selected is determined by the type of alloy poured. For alloys that are very sensitive to high velocities and turbulence, such as aluminum and some copper-based alloys, a gating ratio of 1:4:4 is recommended.

   This ratio is commonly used in industry and will be used in the material that follows. A ratio of 1:2:2 also provides an unpressurized system and may be more appropriate for the smaller flasks used in school foundries.

9. *Risers:* **Risers** should be used *only* when necessary (when castings have thick sections). When used, they should be of an appropriate size (with a smaller surface-area-to-volume (SA/V) ratio than the casting or casting section to be fed) and should be placed on the sprue side of the cavity (so some of the last-poured or hottest metal goes into the riser).

10. *Vents, whisker vents, flowoffs:* **Vents, whisker vents, flowoffs,** and so on, are used as necessary to evacuate the mold cavity and gating system of air and gases ahead of the molten metal.

Some alloys will produce fair castings in spite of poorly designed gating systems. Among these are red and yellow brass and gray iron. However, alloys that form tenacious oxide skins, such as aluminum, aluminum bronze, and manganese bronze, require the carefully designed gating system described above if high scrap loss is to be avoided.

NINE SIMPLE STEPS TO A CALCULATED GATING SYSTEM

What follows is a *simplified* approach to calculating gating systems that leaves out much of the tedium, yet results in a gating system that is basically consistent with principles proposed by the American Foundrymen's Society based on its research.

Calculations start with the choke, which is usually the CSA of the bottom of the sprue (Fig. 4-4).

Step 1

Determine the CSA of the choke (CSAC)
If the choke is square or rectangular the formula is

Formula: $\text{CSAC} = W \times L$

For example,

$$\begin{aligned}\text{CSAC} &= \tfrac{3}{8}\text{ inch} \times \tfrac{1}{2}\text{ inch}\\ &= \tfrac{3}{16}\text{ square inch (approximately 0.2 square inch)}\end{aligned}$$

If round, find the diameter in the chart of diameters and areas of circles (Fig. 4-5) and determine the area.

Diameter (Inches)	Decimal Equivalent	Area (Square Inches)
29/64	.453125	.16126
15/32	.468750	.17257
31/64	.484375	.18427
1/2	.500000	.19635
33/64	.515625	.20880
17/32	.531250	.22166
35/64	.546875	.23489

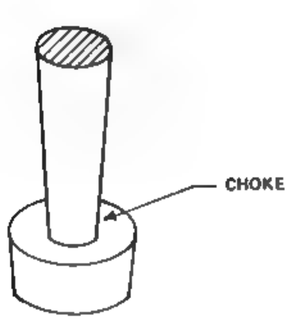


Figure 4-4
The bottom of a tapered downsprue provides an effective choke.

Dia. In.	Decimal Equiv.	Area Sq. In.	Dia. In.	Decimal Equiv.	Area Sq. In.
1/4	.250000	[illegible]	1	1 00000	0.7854
17/64	.265625	.05541	1 1/16	1.06250	[illegible]
9/32	.281250	.06213	1 1/8	1.12500	0 9940
19/64	[illegible]	.06922	1 3/16	1 18750	1.1075
5/16	.312500	.07670	1 1/4	1.25000	1.2272
21/64	.328125	[illegible]	1 5/16	1.31250	1.3530
11/32	.343750	[illegible]	1 3/8	1.37500	1.4849
23/64	.359375	.10144	1 7/16	1.43750	1.6230
[illegible]	.375000	.11045	1 1/2	1.50000	1.7671
25/64	.390625	.11985	1 9/16	1.56250	1 9175
13/32	.406250	.12962	1 5/8	1.62500	2.0739
27/64	.421875	.13979	1 11/16	1.68750	2.2365
7/16	.437500	.15033	1 3/4	1.75000	2.4053
29/64	.453125	.16126	1 13/16	1.81250	2 5802
15/32	468750	.17257	1 7/8	1.87500	2 7612
31/64	.484375	.18427	1 15/16	1.93750	2 9483
1/2	.500000	.19635	2	[illegible]	3.1416
33/64	.515625	.20880	2 1/16	2.06250	3 3410
17/32	.531250	.22166	2 1/8	2.12500	3 5466
35/64	.546875	.23489	2 3/16	2.18750	3 7583
9/16	.562500	.24850	2 1/4	2 25000	3.9761
37/64	.578125	.26248	2 5/16	2.31250	4 2000
19/32	.593750	.27688	2 3/8	2.37500	4.4301
39/64	609375	.29164	2 7/16	2.43750	[illegible]
5/8	625000	30680	2 1/2	2.50000	5 0987
41/64	.640625	.32232	2 9/16	2.56250	5.1572
21/32	.656250	.33824	2 5/8	2.62500	5.4119
43/64	.671875	.35453	2 11/16	2.68750	5 6727
11/16	687500	.37122	2 3/4	2.75000	5 9396
45/64	.703125	[illegible]	2 13/16	2.81250	6.2126
23/32	718750	.40574	2 7/8	2.87500	6.4918
47/64	.734375	.42356	2 15/16	2.93750	6.7771
3/4	.750000	.44179	3	3.00000	7.0686
49/64	.765625	.46041	3 1/16	3.06250	7 3662
25/32	.781250	.47937	3 1/8	3 12500	7.6699
51/64	.796875	.49872	3 3/16	3 18750	7 9798
13/16	.812500	.51849	3 1/4	3.25000	[illegible]
53/64	.828125	.53862	3 5/16	3.31250	8.6179
27/32	.843750	.55914	3 3/8	3 37500	8 9462
55/64	.859375	.58003	3 7/16	3.43750	9.2806
7/8	875000	.60132	3 1/2	3 50000	9 6211
57/64	[illegible]	.62298	3 9/16	3 56250	[illegible]
29/32	.906250	.64504	3 5/8	3.62500	10 3210
59/64	.921875	.66746	3 11/16	3.68750	10.6800
15/16	.937500	.69029	3 3/4	3.75000	11 0450
61/64	.953125	.71349	3 13/16	3.81250	11.4160
31/32	.968750	.73708	3 7/8	3.87500	11.7930
[illegible]	.984375	.76097	3 15/16	3 93750	12 1770
			4	4.00000	12.5660

Figure 4-5
Diameters and areas of circles.

For example,

$$\text{CSAC} = 0.19635 \text{ square inch}$$
$$\text{(approximately 0.2 square inch)}$$

The following formula can be used if you want to practice some mathematical skills:

$$\begin{aligned} \text{Formula:} \quad \text{CSAC} &= \pi r^2 \\ \text{CSAC} &= 3.1416 \times (.25)^2 \\ &= 3.1416 \times 0.0625 \\ &= 0.19635 \text{ or } 0.2 \text{ square inch} \end{aligned}$$

NOTE: The above size of 0.2 square inch produced by a round tapered sprue cutter with a smaller diameter of ½ inch is the recommended size choke for most castings of the size made in school foundries. Larger-than-normal school foundry castings could use a round tapered sprue cutter with a smaller diameter of ⅝ inch. This provides a choke of 0.3 square inch. If the size of the choke is not calculated from casting weight and thickness, fluidity of the metal, effective sprue height, and so on as described earlier, the above (*recommended*) sizes will work for most school foundry work.

Step 2

Calculate the *CSA* of the sprue base (CSASB).
The formula for calculating the CSA of the sprue base (CSAB) is:

$$\text{Formula:} \quad \text{CSASB} = \text{CSAC} \times 5$$

For example,

$$\begin{aligned} \text{CSASB} &= .2 \times 5 \\ &= 1.0 \text{ square inch} \end{aligned}$$

NOTE: Most sprue bases are round, but a square configuration can be used.

Step 3

Determine the diameter of the sprue base (DSB). Take directly from the chart of diameters and areas of circles (Fig. 4-7).

Diameter (Inches)	Decimal Equivalent	Area (Square Inches)
1	1.00000	0.7854
$1\frac{1}{16}$	1.06250	0.8866
$1\frac{1}{8}$	1.12500	0.9940
$1\frac{3}{16}$	1.18750	1.1075
$1\frac{1}{4}$	1.25000	1.2272
$1\frac{5}{16}$	1.31250	1.3530
$1\frac{3}{8}$	1.37500	1.4849
$1\frac{7}{16}$	1.43750	1.6230
$1\frac{1}{2}$	1.50000	1.7671

Alternatively, you can use the following formula to sharpen your mathematical skills.

Formula: $$DSB = \sqrt{\frac{A}{0.7854}}$$

$$DSB = \sqrt{\frac{1.0}{0.7854}}$$
$$= \sqrt{1.2732}$$
$$= 1.128 \text{ or } 1\tfrac{1}{8} \text{ inches}$$

Step 4

Calculate the total CSA of the runner(s) (T CSAR)
To calculate the total CSA of the runner, use the formula:

Formula: $T\ CSAR = CSAC \times 4$

For example,

$$T\ CSAR = .2 \times 4$$
$$= 0.8 \text{ square inch}$$

Example 1: One runner (Fig. 4-6)

NOTE: Since a runner for aluminum, brass or iron should be wider than it is deep, reasonable dimensions for this runner would be 1.1 inches wide and 0.7 inch deep *at this point* in the runner system.

Example 2: If 2 runners come from the sprue base (Fig. 4-7), they would each be ½ the *total* CSA of the runner or, in this case 0.4 square inch.

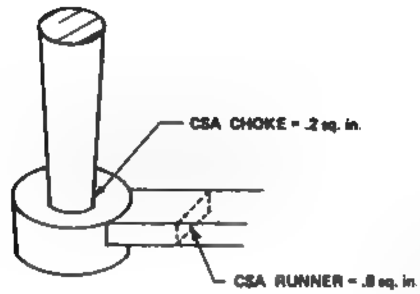


Figure 4-6
The CSA of a one-runner system is 4 times the CSA of the choke.

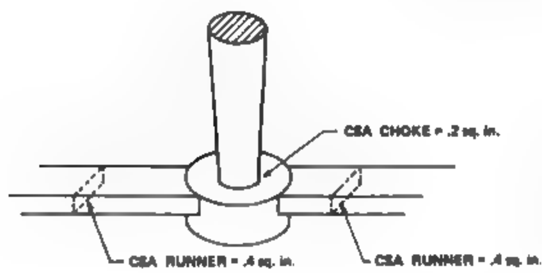


Figure 4-7
Each runner of a two-runner system is 2 times the CSA of the choke.

NOTE: Runners 1.0 inch wide × 0.4 inch deep or with some other combination of dimensions that equals 0.4 square inch and provides for a wide, shallow runner would be appropriate.

Step 5

Calculate the depth of the sprue base (SBD)
The formula for calculating the depth of the sprue base (SBD) is:

$$\text{SBD} = \text{Depth of Runner} \times 2$$

Example 1: *One* runner (Fig. 4-8)

$$\begin{aligned}\text{SBD} &= .7 \text{ inch} \times 2 \\ &= 1.4 \text{ inch}\end{aligned}$$

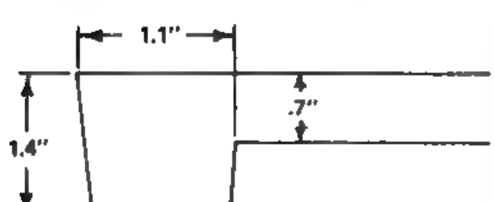


Figure 4-8
Having selected runner width and depth dimensions to provide the desired CSA enables one to calculate the depth of the sprue base.

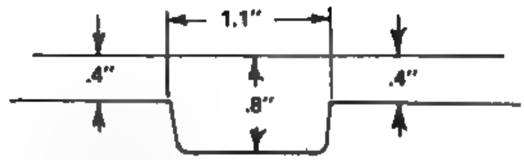


Figure 4-9
With a two-runner system, the diameter of the sprue base is unchanged but its depth is decreased.

Example 2: *Two* runners (Fig. 4-9)

$$\begin{aligned} SBD &= .4 \text{ inch} \times 2 \\ &= .8 \text{ inch} \end{aligned}$$

Step 6

Calculate the total CSA of the gates (T CSAG)
The total CSA of the gates (T CSAG) is 4 times the CSA of the choke.

Formula: $\text{T CSAG} = \text{CSAC} \times 4$

For example,

$$\begin{aligned} \text{T CSAG} &= .2 \times 4 \\ &= .8 \text{ square inch} \end{aligned}$$

Step 7

Calculate the CSA of *each individual gate* (CSAIG) (see Fig. 4-10).

When we know the total CSA of the gates, we can calculate the CSA of each individual gate (CSAIG). The formula is:

Formula: $\text{CSAIG} = \dfrac{\text{T CSAG}}{\text{Number of gates}}$

For example,

$$\begin{aligned} \text{CSAIG} &= \frac{.8}{4} \\ &= .2 \text{ square inch} \end{aligned}$$

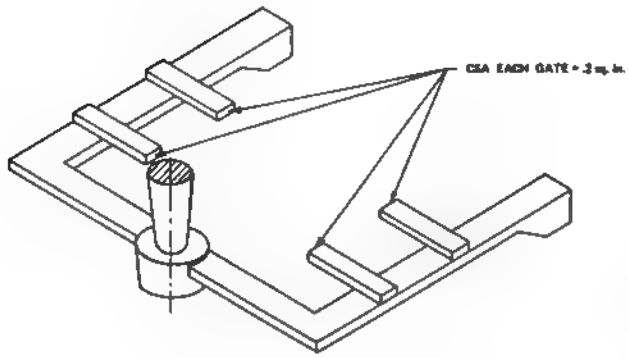


Figure 4-10
The total CSA of gates is divided by the number of gates to determine the CSA of each individual gate.

NOTE: Gates should be wide and shallow. An appropriate size for the example given would be 0.6 inch wide × 0.3 inch deep or some other combination of dimensions that would equal 0.2 square inch and provide the desired configuration.

Step 8

Determine the amount of taper for the runner. Theoretically, the CSA of the runner should be *stepped down* or decreased by the CSA of each gate immediately after that gate is passed—except for the last gate (the gate farthest from the sprue) (see Fig. 4-11).

This provides for approximately equal amounts of metal entering the cavity through each gate.

A simplified approach that achieves the same thing is to taper the runner from the calculated CSA at point x to the CSA of the individual gate at point y or, in our example, from 0.8 square inch to 0.2 square inch.

Using our example, if the dimensions of the runner at x are 1.1 inches × 0.7 inch (0.8 square inch) the dimensions at y are 1.1 inches × 0.2 inch deep (0.2 square inch).

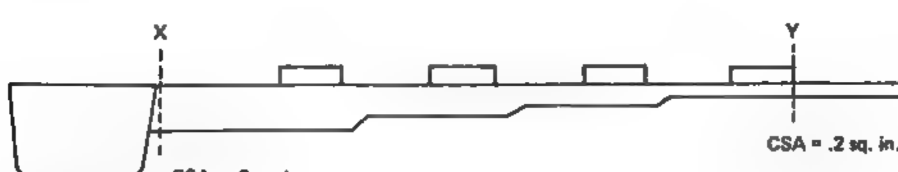


Figure 4-11
A stepped-down runner.

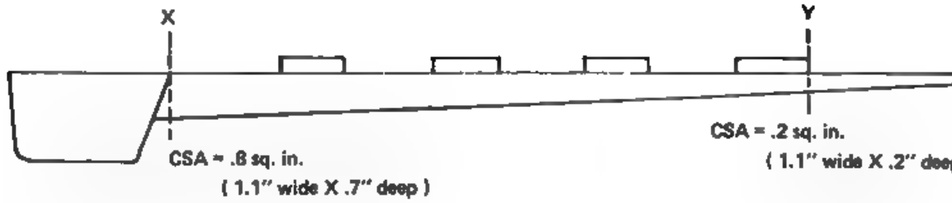


Figure 4-12
A tapered runner that is easier to make and more effective than a stepped-down runner.

The runner would then look like that shown in Figure 4-12. Such a runner is not only easier to make but will actually provide less turbulence than the traditional stepped-down runner.

Step 9

Provide for a runner extension or sump beyond the last gate.

The first metal poured (which is inevitably damaged and cold) should not enter the mold cavity. To make sure that the first metal poured remains in the gating system, it is necessary to provide a sufficiently large runner extension or sump beyond the last gate on each runner.

If flask size permits, provide for a runner extension by continuing the runner for 6 inches beyond the last gate, maintaining the CSA of the runner at that gate (Fig. 4-13). If this is inconvenient, it is necessary to develop a sump that will hold an equivalent amount of molten metal.

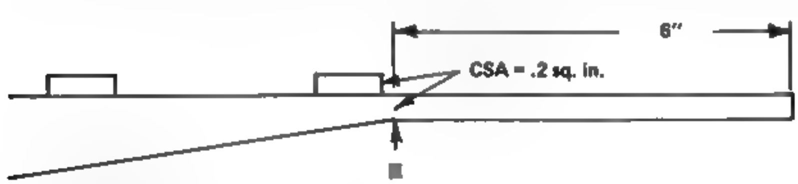


Figure 4-13
The recommended length for a runner extension is 6 inches beyond the last gate.

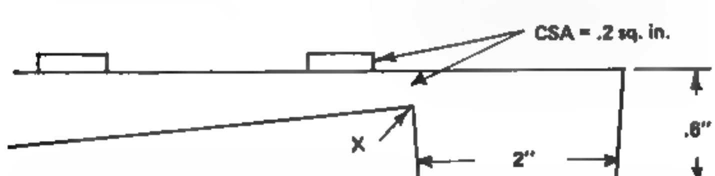


Figure 4-14
If space is limited, a sump can be designed to provide for the same volume of metal accommodated by a proper length runner extension.

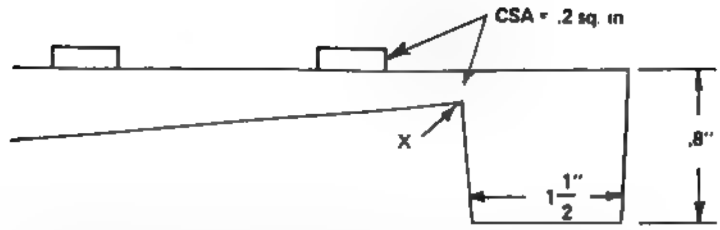


Figure 4-15
An even deeper sump can be made if necessary. Such runner extension sumps are especially appropriate when using small flasks.

Example 1: If you can go only 2 inches beyond the last gate, make the sump 3 times as thick as the runner at point x (Fig. 4-14).

Example 2: If you can go only 1½ inches beyond the last gate, make the sump 4 times as thick as the runner at x (Fig. 4-15).

RISERING

Need for Risers

After molten metal has been poured into a mold, it starts to cool; as it cools, it contracts or gets slightly smaller. This is known as **liquid shrinkage.** Liquid shrinkage continues until the metal reaches the temperature at which it starts to solidify.

Most metals and alloys solidify through a *range of temperatures* (rather than at a certain specific temperature), and most of them contract or shrink during this time. This is known as **solidification shrinkage.**

After solidification has been completed, the casting continues to shrink as it cools to room temperature. This is called solid shrinkage.

The patternmaker solves the problem of solid shrinkage by making the pattern just oversize enough to compensate for it. Liquid and solidification shrinkage are problems that must be solved as the green sand mold is made.

Most metals and alloys start to solidify at the mold wall where the chilling effect of the sand causes a skin to develop. Solidification progresses from the skin through columnar growth (Fig. 4-16) and dendritic growth (Fig. 4-17) toward the center of the casting. This process is called **progressive solidification.** *At the same time,* solidification moves from the sections of the casting farthest from the supply of molten metal *in the direction* of that supply. This is known as **directional solidification.** The result of these two types of solidification is that the casting solidifies last somewhere near the center of its thickest part. Unless molten metal

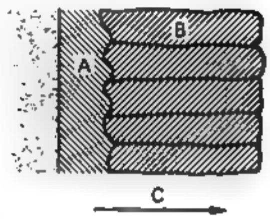


Figure 4-16
Columnar growth. *A*, Chill Zone. *B*, Columnar growth. *C*, Direction of growth.

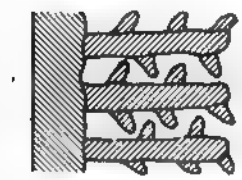


Figure 4-17
Dendritic growth.

is supplied to this area, the casting will have shrinkage defects. Since the pouring operation is completed *before* this need for extra metal arises, the metal to feed the problem area must come from reservoirs of molten metal that are a part of the gating system. Such reservoirs are called risers, and the main requirement of a riser is that the metal in it stay molten longer than the part of the casting it is to feed.

Many castings poured in the school foundry are small and thin or fairly uniform in cross section. Such castings *do not* require risers for controlling shrinkage, nor are risers needed to indicate that the mold is full. One or more risers *should* be used when the casting has one or more sections that are substantially thicker or heavier than the rest of the casting.

Types of Risers

There are two kinds of risers, **side risers** and **top risers** (Fig. 4-18). Top risers are problematic in that they are more expensive to remove and more difficult to keep molten. As a result, they are used only as a last resort. Side risers are much more commonly used, and all the information about risers in this book will pertain to side risers.

Figure 4-18
Left side riser Right top riser.

Shapes of Risers

Since it is very important that a riser remain molten longer than the part of a casting it is designed to feed, a riser shape that retards solidification should be selected. A riser loses most of its heat by coming in contact with moist sand. Therefore, a shape that provides the largest volume of metal with the smallest surface area loses heat most slowly. This shape is a sphere or ball, but although spherical risers are used to some extent, their use in production molding operations is problematic and very limited. The shape with the next best surface-area-to-volume ratio is the cylinder. Most risers are cylindrical.

Determining the Size of Risers and Their Parts

The size of the risers (and their parts) should be determined by calculations rather than by guessing.

Diameter: The diameter of a riser depends on many different factors. For our purpose, it is enough to select a size somewhat larger than the heavy section of the casting the riser is to feed. Risers, when needed for school foundry castings, are often made very much undersize.

Height: Once the diameter is determined, the height of a riser can be calculated easily. It should be no shorter than ½ its diameter and no longer than 1½ times its diameter.

Bulb: The bottom of the riser (**bulb**), is rounded with its radius equal to that of the riser's cylinder. This maintains a favorable surface-area-to-volume ratio, which helps to preserve heat in the riser (Fig. 4-19).

Dome: Many risers are **open,** in that they extend to the top of the cope. After pouring, such risers are sometimes covered with dry sand to retard their cooling and thus ensure that they can feed metal to a potential shrink. Another means of retarding cooling is to form risers that do not extend to the top of the cope. These are called **blind risers.** Such risers should be designed with a **dome.** The dome is the top of the riser. It is rounded and its radius is that of the riser's cylinder (Fig. 4-20). A prop-

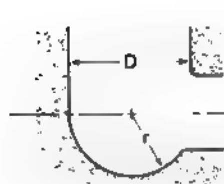


Figure 4-19
Bulb, or bottom of riser.

Figure 4-20
Dome, or top of riser.

erly designed blind side riser with its rounded bulb and dome is a rough approximation of a sphere or ball. Such a riser tends to keep the metal molten (and feeding) for a long time since it has a small surface area compared with its volume.

Neck: Metal flows from the riser to the casting through the **neck.** If the neck for a side riser is too small or too long, metal may solidify too soon, preventing the riser from doing its job. On the other hand, excessively large side riser necks increase removal costs.

Round Riser Necks

Many foundries design round riser necks no longer than 1 inch in length (Fig. 4-21). This "rule of thumb" is quite useful in the school foundry. In industry, where risers are often 6 inches in diameter and larger, the length of the riser neck (LRN) should never exceed ½ the diameter of the riser (DR). The diameter of a riser neck (DRN) is calculated as follows:

$$\text{DRN} = 1.2 \times \text{LRN} + 0.1 \times \text{DR}$$

Example: If the riser is 2 inches in diameter:

$$\begin{aligned}\text{DRN} &= 1.2 \times 1 + (0.1 \times 2)\\ &= 1.2 + .2\\ &= 1.4\end{aligned}$$

Square or Rectangular Riser Necks

If a riser is to have a rectangular or square neck, the calculations are somewhat different.

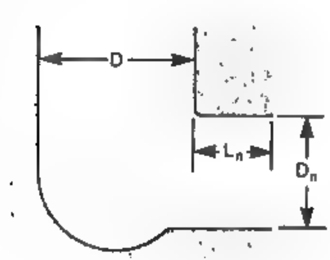


Figure 4-21
Determining diameter of round riser necks.

Length of riser neck (LRN) = ⅓ × RD

Width of riser neck (WRN) = (2.5 × LRN [length of riser neck]) + (0.18 × RD)

Height of the riser neck (HRN) = 0.7 × thickness of casting

Example: If a 3-inch diameter side riser is to be used with a 2-inch thick casting:

$$
\begin{aligned}
\text{LRN} &= \tfrac{1}{3} \times 3 \\
&= 1 \\
\text{WRN} &= (2.5 \times 1) + (0.18 \times 3) \\
&= 2.5 + 0.54 \\
&= 3.04 \\
\text{HRN} &= 0.7 \times 2 \\
&= 1.4
\end{aligned}
$$

Location of Risers

Even when risers are properly sized, they cannot work effectively (to relocate shrinkage from the casting to the riser) unless they are also properly placed. Risers that are placed downstream from the cavity contain some of the first metal poured down the sprue. This metal has been cooled by its contact with moist sand as it travels through the mold. As a result, it may solidify *before* the casting does. If so, it will be ineffective. Such risers are called **cold** or **dead risers.** Some effort must be made to prevent the riser from solidifying *before* the casting. Using blind risers or special sleeves to insulate the riser metal from the moist sand are common techniques. Another is adding an exothermic (heat-producing) material to the top of the riser.

Because of the problems associated with cold or dead risers, it is more common to use risers that are placed *between* the sprue and the cavity. In this position, some of the last poured (hottest) metal ends up in the riser. Such rises are called **hot** or **live risers.** Properly designed hot or live risers require little in the way of special attention and are most effective in relocating shrinkage from the casting to the riser. The neck of such a riser often is used as the gate closest to the sprue.

CHILLS

Chills are another way to control shrinkage and achieve directional solidification. Chills are used with ferrous as well as nonferrous metals and alloys in industry, but are rarely used in the school foundry. An **external chill** is a piece of material (usually metal) that conducts heat well, placed

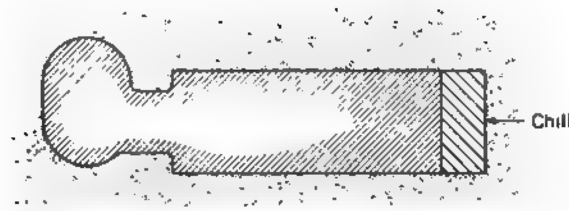


Figure 4-22
External chill.

in the mold so that it serves as the mold wall (Fig. 4-22). It is located at the point where solidification should start first and progress rapidly. It is important that the melting point of the external chill be substantially higher than the metal in the casting. Also, care must be taken to prevent a metal chill from fusing or sticking to the casting. This is usually achieved by coating the chill with a wash of some kind.

Internal chills are also used. These devices are pushed into the side wall of a mold so that the largest mass of the chill protrudes into the mold cavity (Fig. 4-23). Internal chills should be made of a metal that is compatible with the metal in the casting. As the metal is poured and the metal surrounds the internal chill, the chill is either melted or entrapped. In either case, the mass of cold metal provided by the internal chill promotes solidification.

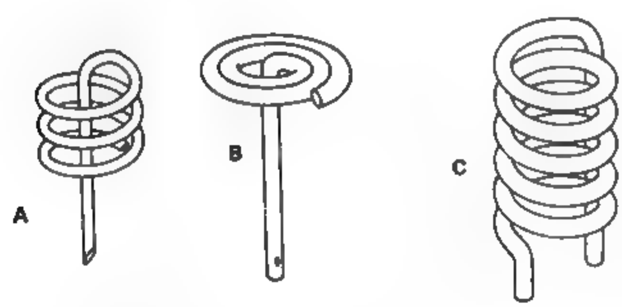


Figure 4-23
Internal chills. *A,* Chill coil nail. *B,* Flathead chill coil nail. *C,* Hub chills.

OTHER CONSIDERATIONS AND REMINDERS

Sometimes a casting turns out good *in spite of* a poor gating system. Such an accident does not invalidate the need for properly designed gating systems—especially when using alloys that form tenacious oxide skins when molten. If you were to make a number of castings (as is done in industry) using a poorly designed gating system, you would probably produce a very few accidentally good castings and many scrap castings.

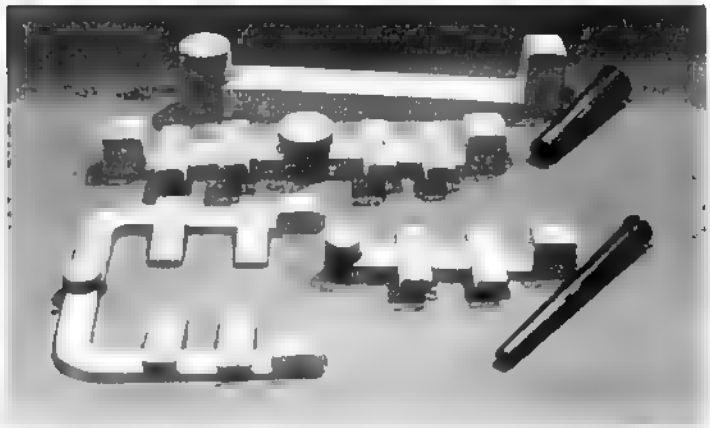


Figure 4-24
Loose pieces of CALCULATED gating systems.

- Be sure to locate runners in the drag and gates in the cope.
- If possible, have about 6 inches of runner from the sprue base to the first gate.
- Think of a casting as a wedge and gate into the thickest part of the casting. This will promote desirable directional solidification.
- Try to locate gates and risers where removal will be simplified. Don't gate into a portion of the mold where there is a lot of detail.
- Be sure to provide a runner extension or sump of sufficient size to prevent the first metal poured from going into the mold cavity.
- Cut a vent (flowoff or whistler) through the cope above the runner extension or sump to eliminate gas pressure buildup.
- Horseshoe runners are more effective with streamlined, rounded corners; however, gates located at 90-degree angles to runners are about as effective as streamlined runners.
- Much turbulence results from metal flowing through rough, hand-cut gating systems. When molding loose patterns, use loose pieces of a gating system to produce smoother channels (see Fig. 4-24).

TEST YOUR KNOWLEDGE

T-F **1.** Quiet metal flow requires low velocity and little turbulence.

T-F **2.** The first metal poured into a gating system is damaged and should be retained in the gating system.

3. When pouring molds, metal should be poured from the crucible into a ________ ________.

4. It is important that the sprue be ________.

T-F 5. A flat-bottom sprue base is better than one that is slightly convex.

T-F 6. Runners should be wide and deep.

7. Runners should be located in the ________ ; gates, in the ________ .

8. The suggested ratio for unpressurized gating systems is 1:__ :__ .

9. The CSA of the sprue base should be ________ times the CSA of the choke.

10. The depth of a sprue base should be ________ times the depth of the runner(s).

T-F 11. Gates should be wide and shallow.

12. To ensure that approximately equal amounts of metal enter the mold cavity through each gate, runners should be stepped down or ________ .

T-F 13. A stepped-down runner is one in which the CSA of the runner is decreased by the CSA of the gate just *before* the gate.

14. The recommended length for a runner extension is ________ inches beyond the last gate.

15. If the flask size does not permit a runner extension of the recommended length, a ________ can be designed to hold an equivalent amount of molten metal.

16. Solidification that takes place *from* the sections of the casting farthest from the supply of molten metal, *toward* the supply of molten metal is called ________ solidification.

T-F 17. The diameter of a riser should be smaller than the heavy section of the casting it is to feed.

18. The height of a riser should be no shorter than ________ times its diameter.

19. The rounded bottom of a riser is called the ________.

20. The rounded top of a blind riser is called the ________ .

21. Molten metal in a riser feeds to a potential shrink through its ________ .

22. A good rule of thumb pertaining to riser neck length is "no longer than ________ inch."

CHAPTER 5

Green Sand Molding

*Foundry Sand • Sand-Conditioning Equipment • Sand Testing •
Equipment Used in Making Sand Molds •
Tools Used in Making Sand Molds • Molding*

CHAPTER GOALS

After studying this chapter you should be able to:

1. State the main difference between natural bonded and synthetic foundry sand.
2. Give at least one advantage and one disadvantage of the following different foundry sands:
   - Natural bonded
   - Oil-tempered (waterless)
   - Olivine
3. Describe how the moisture content is determined with an oven test.
4. Explain how sand-test results from more than one test can be used to provide additional data.
5. List at least four molding tools or devices that are used when working with loose patterns.

TERMS TO KNOW (see Glossary)

Natural foundry sand
Synthetic foundry sand
Oil-tempered (waterless) foundry sand
Silica foundry sand
Olivine foundry sand
Standard AFS sand specimen
Sand rammer
Green compression strength
Permeability
Mold hardness
Compactibility
Tube filler accessory
Flask
Bushing
Draft
Loose pattern
Matchplate
Chill
Foundry nails
Sprue cutter
Vibrato
Draw spike
Draw screw
Bulb sponge
OSHA
Bellows
Whisker vents
Whistler (flowoff)
Jolt-squeeze machine

FOUNDRY SAND

The foundry sand used to make green sand molds is *not* green in color. In this case, green means moist. All foundry sand can be classified as **natural** (naturally bonded) or **synthetic.** Synthetic means certain proportions of different substances have been mixed by man as compared with natural sand wherein nature has produced sand mixed with clay in useful proportions.

Natural Bonded Foundry Sand

Natural bonded foundry sand can be used just as it is when dug from the ground. It must be tempered by adding just enough water that a squeezed lump will retain the imprint of fingers, support itself when held by one end, and break with sharp corners. Excessive water added to natural bonded sand will result in substantial amounts of sand sticking to your hand. You will have to rub it with your hand to get it to pass through an eight-mesh riddle. Also, your chances of producing good castings in excessively moist sand are very slim.

This sand is light brown when dry. It is found principally in New York, New Jersey, Tennessee, Ohio, and Mississippi. It is available from suppliers as Tennessee Gold Seal or Albany No. 00 or No. 1. Its advantages lie in its relatively low cost, its long life, and its freedom from smoke and nasty fumes when molds are poured. Its greatest disadvantage is the rather high moisture content (5–7 percent) required for proper tempering.

Natural bonded foundry sand is used industrially in a number of nonferrous foundries. Formerly it was the most commonly used sand in school foundries; however, natural bonded foundry sand has been replaced with **oil-tempered (waterless) foundry sand** (described below) in many school foundries.

Synthetic Foundry Sand

Most of the molding sand used in industrial green sand molding is categorized as synthetic foundry sand. Most of such sand is conditioned or tempered with water, but some is tempered with oil.

Oil-Tempered (Waterless) Foundry Sand: Since the early 1960s, oil-tempered sand has been used in some industrial nonferrous foundries and many school foundries. The ingredients for slightly more than 100 pounds of this sand are:

- Dry, clean, clay-free silica sand of the desired AFS grain fineness number, 100 pounds.
- The binder, a light red, clay-like, flour-type material, 5 pounds.
- Lightweight (No. 10) nondetergent oil, 2 pounds.
- The catalyst, methyl alcohol or Catalyst P-1, 1 ounce.

Use the following procedure to produce a new batch of sand:

1. Place weighed amount of sand in muller and add correct amount of clay-like binder.
2. Mull for 1 minute.
3. Add oil.
4. Mull 5 minutes.
5. Add catalyst and mull for another 3 minutes.

NOTE: This should provide green compression strength (tenacity) of 10–11 pounds per square inch (psi).

Newly mixed sand is light red. As sand is used, it darkens to a black color. The color is unimportant. However, when the green strength has dropped to a minimal level (as evidenced by occasional drops or sand being eroded by molten metal), the sand must be revitalized. Additions of 1 percent binder, 1 percent oil, and catalyst at the rate of 1 ounce (28 grams) per 100 pounds (45 kilograms) of sand, used with the mixing schedule given above, should provide satisfactory green strength.

Some of the reasons this sand is popular are:

- It produces good detail and surface finish on castings.
- It produces dense metal in the casting.
- It is strong, which allows deep pockets to be lifted successfully.
- It can be rammed very hard without danger of blows (see Chapter 7).
- It can be used without reconditioning (except for aerating and riddling) between successive molds.
- It saves preparation time at the beginning of a class period because it does not dry out.

- Inexperienced students can avoid the problem of trying to condition sand properly.

Some disadvantages of oil-tempered (waterless) sand are:

- It is expensive when purchased mixed. However, dramatic savings can occur if the raw materials are purchased and mixed in mulling equipment at the school or a nearby foundry.
- It is "dirty"; after working with it, hands are difficult to clean.
- It causes large amounts of smoke when molds are poured—if an adequate ventilation system does not exist, the air will turn blue.
- Its application is limited to nonferrous metal, and higher-temperature copper-base alloys burn out the oil very much faster than the lower-temperature aluminum alloys.
- Molds opened too soon constitute a safety hazard, because the oil in the sand burns vigorously. Shakeout must be executed carefully.

NOTE: Sand adjacent to the casting becomes burned black. That which sticks to the casting or is left in the mold should be discarded. This can be tedious, but unless mulling equipment is available, the burned sand must be eliminated or the green compression strength of the sand will be lowered rapidly.

For *best* performance, the sand should be screened to remove foreign matter and mulled (not just mixed) each time it is used.

Silica Foundry Sand: School foundries that have mulling equipment and are familiar with the disadvantages of the high moisture content required by natural sand and the air polluting effects of pouring molten metal into molds made of oil-tempered sand might want to consider using a water-base synthetic sand. It eliminates the main disadvantages of the two sands described above.

Most industrial foundries use **silica foundry sand** for molding. The three basic ingredients are silica sand, clay, and water. Small proportions of wood flour, cereal, and seacoal are sometimes added for expansion control or to achieve improved surface finish. In this way the sand is tailored to best fit the needs of the type and mass of metal being cast and the surface finish desired.

A silica sand mixture suitable for aluminum castings of the size commonly made in the school foundry is:

- 100 pounds (45 kilograms) AFS Gr. Fn. No. 90–180
- 5 pounds (2.26 kilograms) southern bentonite
- 3 pounds (1.35 kilograms) water

Slightly different recipes for the production of small copper-base alloy or gray iron castings are available in reference books.

A mulling schedule appropriate for the above recipe in a vertical wheel muller is:

1. Add sand and water to muller.
2. Mull for 1–2 minutes.
3. Add clay and other additives.
4. Mull for 3–5 minutes.

NOTE: All newly mixed foundry sands have to go through a break-in period. They perform better with use and then arrive at a point where new ingredients (in small amounts) must be added to retain the desired performance.

Olivine Foundry Sand: Another water-base synthetic sand used in industry that works very well in school foundries with mulling equipment is **olivine foundry sand.** Olivine is a greenish-gray sand with sharp angular grains. It is highly durable, more resistant to fracture from thermal shock, and exhibits substantially less thermal expansion than does silica sand.

The following simple recipe (for a 100-pound batch) will provide an excellent molding material for nonferrous metalcasting.

- Olivine sand of desired AFS grain fineness number, 91 pounds
- Water, 3 pounds
- Southern bentonite, 3 pounds
- Western bentonite, 3 pounds

In mulling a new batch, it is recommended that the sand and water be mulled and then the dry binders added. Time for initial mulling with a vertical wheel muller is 1 minute. Mulling time *after* addition of dry binders is 6–8 minutes.

Advantages of olivine foundry sand are:

- Low moisture content reduces casting defects such as "blows."
- It can be rammed very hard—beginners do not have to learn the "gentle art" of ramming.
- Sharp, angular sand grains provide for high permeability, which reduces casting defects caused by trapped gasses.
- It produces a very stable mold, which provides excellent dimensional accuracy.

- It is highly durable—it has a long thermal life.
- It requires only a short mulling time for reconditioning—90–120 seconds in a vertical wheel muller, 30–60 seconds in a speed muller.
- The sand system is easy to maintain; it is necessary to add new sand and new clay together only to maintain the needed volume of sand.
- One simple formulation can be used for both ferrous and nonferrous work.
- It is relatively inexpensive because of long life.
- It is healthier—olivine dust will not cause silicosis or a similar condition.

The disadvantages of olivine foundry sand are:

- It must be processed before each use.
- It must be used shortly after mulling or the moisture content falls below usable level.

SAND-CONDITIONING EQUIPMENT

Sand must be conditioned for use. For natural bonded sands that are *mixed with water,* conditioning can be simple: Just cut, turn and hit the sand with the back of a shovel as the sand is sprinkled until the heap is completely blended. The shovel serves as a crude muller when used in this manner and such mulled sand will work well. However, a number of pieces of sand conditioning equipment have been developed to process (screen, blend, mull, and aerate) sand more effectively and with less physical effort. In industry, such equipment is often very large or sophisticated.

Gyratory Riddle

In the school foundry, the gyratory riddle is useful for screening and aerating the sand (Fig. 5-1).

Muller

A still more desirable piece of sand-conditioning equipment is the vertical-wheel, batch-type muller (Fig. 5-2), whose plowing and kneading action coats sand grains with a film of clay.

Figure 5-1
Gyratory riddle (made by a metalcasting teacher).

Shovel

The molder's shovel is lightweight and has a semiflat blade approximately 10 inches by 12 inches (250 millimeters by 300 millimeters) with a square nose and a shovel handle grip that is wedge shaped for ramming sand. Any small, flat-bladed, square-nosed shovel will do.

Sprinkling Can

Any galvanized or plastic container for sprinkling, available in hardware stores, will do.

SAND TESTING

Control of several physical properties of foundry sand is critical. Foundry sand is a sensitive material. As a foundry sand is used it changes in several ways. The moisture content changes. Additives that are combustible (cereal, wood flour, seacoal) are consumed by high-temperature metals. The size and distribution of sand grains change as the grains break down

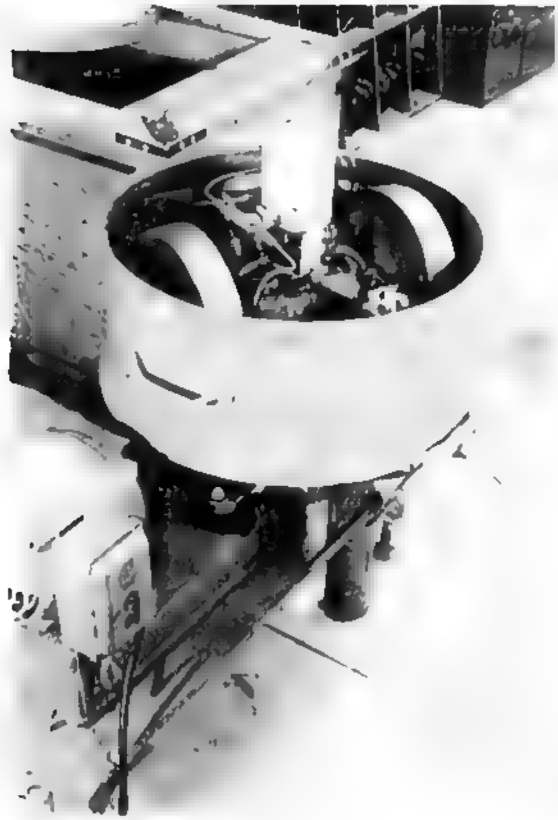


Figure 5-2
Vertical wheel muller—capacity, 50 pounds of sand. The apparatus for dispensing water in front of the wheels was developed by a student.

into smaller pieces. Industrial foundries with tons of sand in their sand systems add new sand, clay, additives, and water to the sand each time it is used, to compensate for some of the changes mentioned above and to replace sand lost in cleaning the castings and in conditioning and transporting the sand. A number of tests are used to control foundry sand and ensure that its properties remain relatively consistent. If a school foundry can acquire some of the more common pieces of sand-testing equipment, instruction in this essential area can be very valuable. Detailed instructions for making specific tests are available from the manufacturers of sand testing equipment, the AFS *Mold and Core Test Handbook,* and reference books. What follows is a brief, general description of how some of the more common sand tests are performed.

Moisture

It is essential to maintain the moisture content of foundry sand within a certain range to keep the quality of castings high. There are several pieces of sand-testing equipment specifically designed to provide moisture data.

Speedy Moisture Tester: A test can be made with the Speedy Moisture Tester device in about 1 minute (Fig. 5-3). A 10-gram specimen of sand is placed in the cap of the tester. One scoop of Speedy Moisture Tester Reagent (powdered calcium carbide) is placed in the body of the tester. The tester is held in a horizontal position and the cap carefully installed so that the sand does not come into contact with the reagent until the tester cap is tightly sealed. Then the tester is turned to a vertical position and shaken 10 times to thoroughly mix the sand and reagent. The moisture in the sand comes into contact with the reagent and produces pressure on a rubber diaphragm. The diaphragm's movement causes the needle to indicate the percentage of moisture on the gauge of the tester. The tester should be returned to a horizontal position after shaking and read immediately. The contents of the tester should be emptied into a waste basket upon completion of the test. Do not put the contents back into the system sand, since the reagent will become a contaminant and produce a rather offensive odor.

Moisture Teller: A more accurate determination of moisture in foundry sand can be made with the Moisture Teller (Fig. 5-4). To use it, you must weigh a 50-gram specimen of sand quite precisely. A laboratory balance has been commonly used, although industry is moving toward newer electronic devices (Fig. 5-5). The drying pan of the Moisture Teller is porous

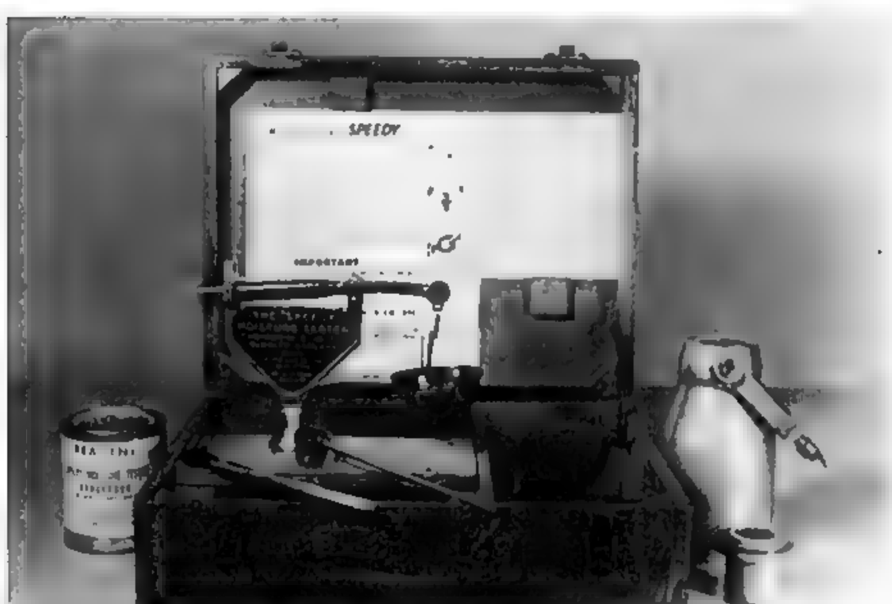


Figure 5-3
The Speedy Moisture Tester provides moisture content information in about one minute.

Figure 5-4
The Moisture Teller blows hot air through a sample of foundry sand to drive off the moisture.

(500-mesh), which allows high-velocity heated air to pass through the sand sample, driving off the moisture. The thermostatic control (which is set at 230F) and a timer ensure consistency from test to test. Subtracting the weight of the dried sand from the original weight and multiplying this amount by two provides the moisture content (in percentage of weight of the tempered sand). Tests like this usually require about 5 minutes—2 minutes for weighing and 3 minutes for drying.

Oven or Heat Lamp Test: The school foundry can determine the moisture content of foundry sand if an oven or heat lamp and an accurate means of weighing samples are available. The system is quite similar to that described above except that the oven or lamp is used in place of the Moisture Teller to dry the sand. The oven temperature should be set to 230F. A 50-gram specimen of sand should dry to a constant weight in about 5 minutes.

Standard AFS Test Specimen

Many sand tests are performed on a **standard AFS test specimen** that is 2 inches in diameter and 2 inches, plus or minus 1/32 inch in length. Such

Figure 5-5
An electronic balance with a digital display, accurate to 1/1000 gram. An empty paper cup was placed on the balance and the control bar pressed which cancelled out the weight of the empty cup and gave a display of zero. Sand was added to the cup until a 50-gram specimen was achieved. This balance is very fast and so accurate that drafts of air will cause the thousandths digit to fluctuate.

a specimen is made by placing a weighed amount (approximately 175 grams) of properly tempered foundry sand into a clean specimen tube and ramming it three times with the **sand rammer** (Fig. 5-6). The resulting sand specimen is left in the tube for some tests and removed from the tube for others by using the stripping post.

Strength

It is important to have some idea of the strength of foundry sand. There are a number of tests to determine various types of sand strength. The most common is **green compression strength.** A properly rammed specimen is removed from the specimen tube and placed in the lower specimen holder of a No. 400 Universal Sand Strength Machine (Fig. 5-7). As the vertical arm and specimen holder are moved up and to the right (with motor or hand crank), weight is brought to bear on the end of the specimen until it breaks. The small magnetic "keeper" that moved up the scale as the test was made remains in place so an accurate reading can be taken.

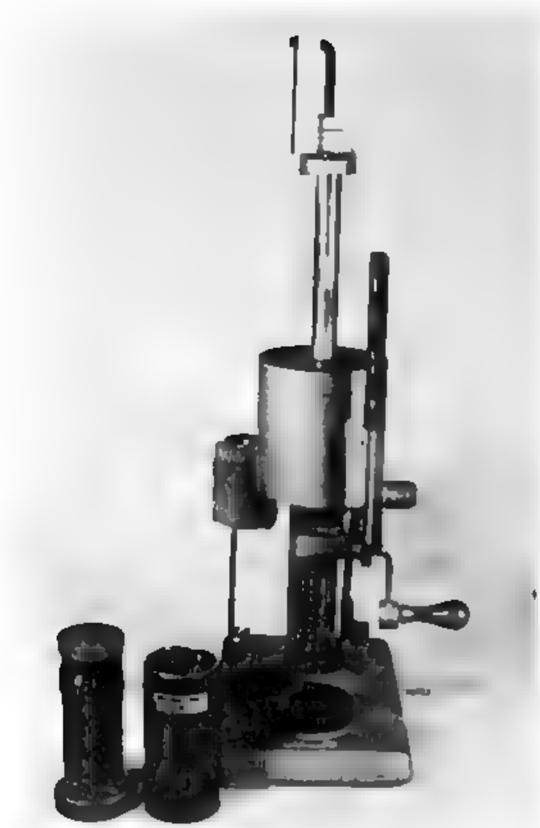


Figure 5-6
A sand rammer. As the hand crank is turned, the large weight rises and falls, packing a given amount of tempered foundry sand in a specimen tube. A standard AFS test specimen is given three rams.

Permeability

Air that is present in the open spaces of a mold and gases formed as molten metal comes in contact with the moist foundry sand must be able to escape, or defective castings will result. Even when rammed to maximum density, foundry sand has some **permeability,** or porousness. The higher the permeability, the easier it is for gases and air to escape *through* the mold. Permeability is affected by the shape of sand grains, by the amount of water, binder, and additives in the sand, and by how hard or dense the sand has been made by ramming. Permeability is determined with a Permmeter (Fig. 5-8) or an electric Permmeter. Permeability is determined by the time required for 2000 cubic centimeters (122 cubic inches) of air (at a pressure of 10 grams per square centimeter) to pass through a standard AFS sand specimen (2 inches in diameter by 2 inches in length). The test is made *before* the specimen is removed from the tube.

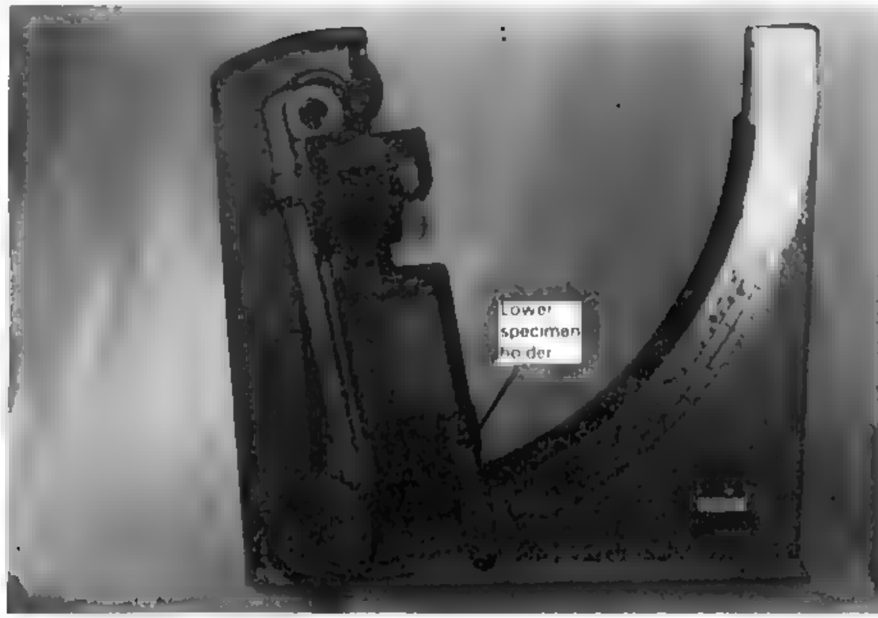


Figure 5-7
A No. 400 Universal Sand Strength Machine set up for conducting a green compression strength test.

Mold Hardness

The surface hardness of a mold can be accurately determined in a matter of seconds with an instrument about the size of a pocket watch. A hard surface (such as glass) registers as 100. Softer surfaces enable a ½-inch ball penetrator to indent the surface. The amount of penetration is indicated on the dial in thousandths of an inch. This tester is used by a technician on the molding floor to check **mold hardness.** In a sand laboratory, the same test can be conducted on a standard AFS sand specimen just prior to its being stripped from the tube while it is resting on the stripping post (Fig. 5-9).

Compactibility

The **compactibility** test is very like the test performed by many molders when they grab a handful of sand and squeeze. An experienced molder becomes very sensitive to various sand conditions and can tell quite a bit about the moisture and green compression strength of sand tested in this manner. A compactibility test is made by filling a standard specimen tube to overflowing with riddled, tempered sand. A **tube filler accessory** ensures that the sand enters the tube after falling a fixed standard distance. A strike-off blade is used to remove the excess sand and the tube is care-

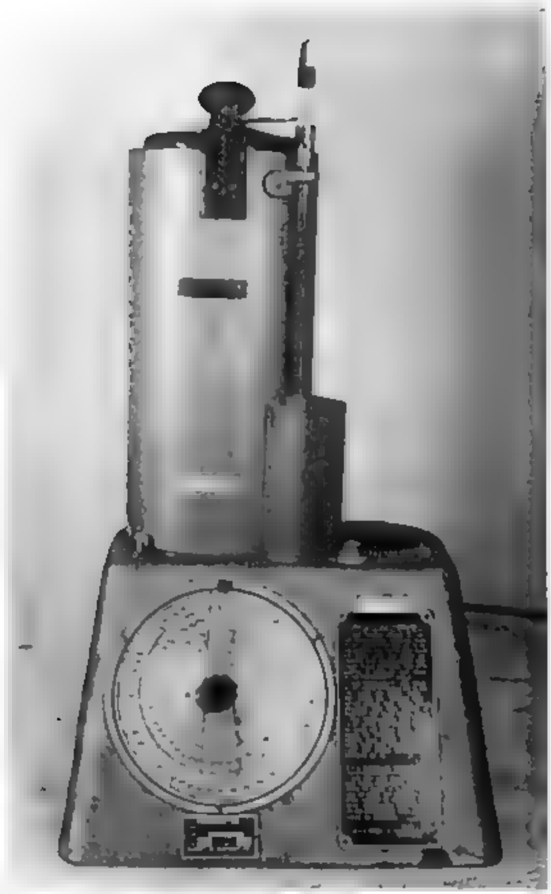


Figure 5-8
A Permmeter, used to determine the permeability (porousness) of a standard AFS test specimen; this device is highly accurate and is used for research and in industry.

fully installed and given three rams on the sand rammer. Compactibility (the percentage of decrease in the original height of the sand) is measured directly if a compactibility accessory (Fig. 5-10) has been installed on the sand rammer. Otherwise, the end of a plastic compactibility scale can be placed down in the specimen tube, against the sand and the compactibility determined in this manner.

Methylene Blue (MB) Test

This is a test that determines the amount of active clay in a sand system. An MB blue test is made as follows:

- Place a 5-gram representative sample of dried system sand into a stainless steel beaker.
- Add 50 milliliters of a 2-percent tetrasodium pyrophosphate solution.

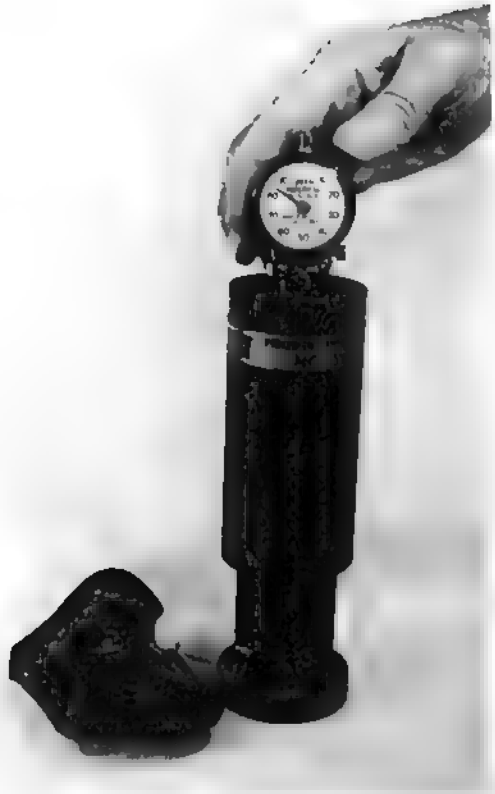


Figure 5-9
Mold hardness tests in the laboratory are performed on the specimen while it is still in the specimen tube—supported by the stripping post.

- Place the beaker in an ultrasonic scrubber and scrub the sand for 5 minutes.
- Add 80 to 90 percent of the estimated amount of methylene blue to the sample and stir with a motor-driven agitator (such as a malted milk machine) for 2 minutes.
- Use a glass rod to place a single drop of the suspension on a sheet of hardened filter paper—a dark blue spot without a blue-green halo on the filter paper indicates that all the methylene blue has been taken up by the clay, and that the end point has not been reached.
- Additions of methylene blue in 1-milliliter increments followed by 2 minutes of stirring continue until a drop of the suspension produces a blue spot that is surrounded by a blue-green halo.
- When the blue-green halo develops, another test drop is made after 2 additional minutes of stirring—a halo similar to the previous one indicates that the clay has taken up all the methylene blue that it

Figure 5-10
Compactibility scale mounted on a sand rammer. The compactibility is read directly from the position of the top of the rod in relation to the scale.

can hold (i.e., the end point has been reached), and that free methylene blue now exists in the suspension.

- Divide the number of milliliters of methylene blue used to achieve end point by the methylene blue calibration factor to determine the percentage of active clay in the sand specimen.

Example: Assuming 24 milliliters of methylene blue have been used to achieve end point, and the calibration factor is 5:

$$5 \overline{)24.0}\quad 4.8$$

The MB test results = 4.8 percent active clay in the system sand.

NOTE: The calibration factor would be close to 5 milliliters of methylene blue per 1 percent of active clay, but must be determined by performing a slightly modified MB test with new clay and sand.

Utilizing Sand Test Data

Although a certain amount of useful information is derived from each specific foundry sand test, sometimes additional information is obtained by combining the results of more than one test. For example, using data from green compression, compactibility, and methylene blue tests with a special slide rule or chart could provide information on effective clay and muller efficiency. Also, since a number of tests are very time consuming, it is sometimes possible to approximate the results to be learned from a long test by using information from several shorter tests. For example, conducting the test to determine the percentage of clay content in foundry sand requires 40–60 minutes. However, with the results of moisture and green compression strength tests (both can be completed in about 5 minutes) the available bond (clay content) can be determined with a special slide rule or chart rather quickly.

EQUIPMENT USED IN MAKING SAND MOLDS

Most industrial molding is accomplished on a machine of some kind. One of the simplest of these is the jolt-squeeze molding machine (Fig. 5-11). Jolt-squeezers that are replaced by more sophisticated molding machines in industry sometimes find their way into school foundries. The machine should have two-hand safety controls to operate the squeeze mechanism. These air-operated machines certainly provide an industrial tone to the molding that is done in a school foundry. Some of the more sophisticated molding machines used in industry include jolt-squeeze-roll-over machines, sand slingers, push-button automatic units, and some units that produce flaskless molds.

In the school foundry, equipment for moldmaking is much less sophisticated. Even so, certain specialized equipment is required.

Molding Bench or Station

A number of commercially made molding benches of wood or metal are available (Fig. 5-12). If you were to visit a commercial foundry, you would see no molding benches like these. In industry, molders often have sand delivered to overhead discharge hoppers through pneumatic tubes, or they get sand from a nearby wheelbarrow or a pile of sand on the floor. However, in school foundries, keeping sand in benches helps to prevent foreign materials produced by other processes from getting mixed into the foundry sand.

A school foundry sometimes has an area separated from the rest of the laboratory by a low wall, with a single entry to the area. There should be a floor grate at the entrance for scraping shoes, so that no foundry sand is carried into the main area and no foreign matter is carried from

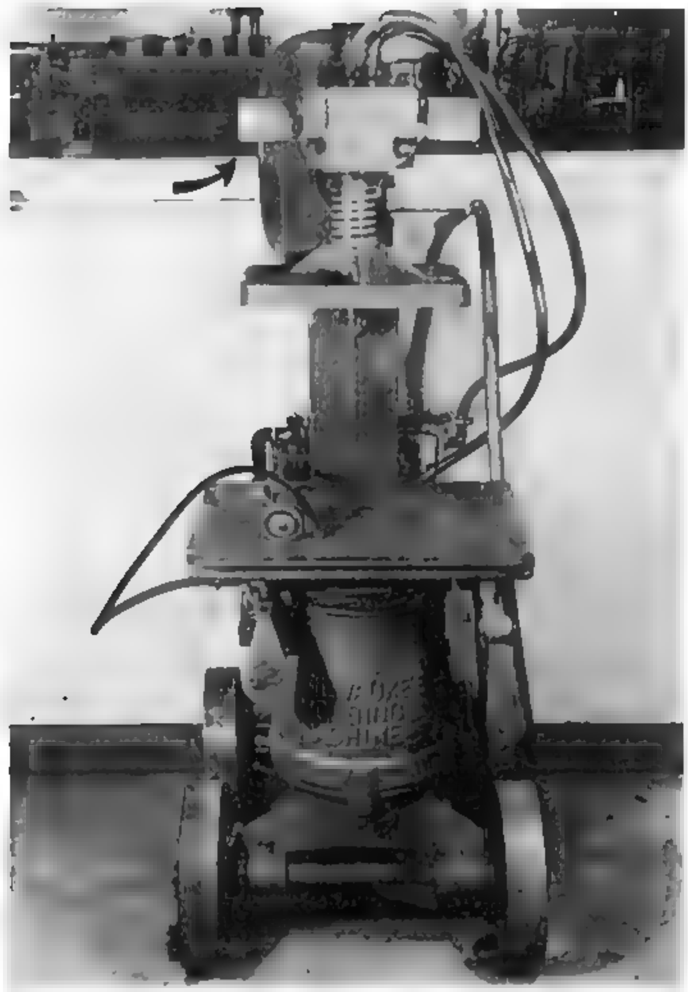


Figure 5-11
Air-operated jolt-squeeze machine. Such a machine in the school foundry provides a realistic industrial tone to instruction since most molds in industrial foundries are made on some kind of a molding machine. Note the two-hand safety controls on the squeeze head.

the main area into the special foundry area. This arrangement permits open molding stations (Fig. 5-13).

Flasks

A **flask** is a boxlike container (without a top or bottom) used to hold sand when making a mold. Some sophisticated equipment in industry permits flaskless molding to be done, but most molds are made in flasks. Generally a flask has two sections, the bottom part (with pins) called the drag,

Figure 5-12
Wood molding bench, metal lined, can be closed to keep the sand from contamination. Shelf and drawer below and shelf above provide storage space for tools and patterns.

and the top part (with **bushings**) known as the cope. *Technically,* the part of the flask that is on the bottom when the mold is poured is the drag whether it has pins or bushings. However, it is less confusing to always identify the part of the flask with pins as the drag. There is an advantage to having the part of the flask with the pins on the bottom, because it is easier to guide the cope into place over guide pins than vice versa. Flasks are commonly rectangular but can be square, round, or some other shape.

Solid flasks are most commonly used in school foundries (Fig. 5-14) and also find substantial use in industry. Such flasks support the mold until it is poured and shaken out. Removable flasks are often used for production molding in industry. These flasks are used only to *make* the mold and are then removed from the mold, which has sufficient strength to stand alone. A mold jacket (Fig. 5-15), which supports the sand and covers the parting line to prevent runouts and shifts, is slipped over the mold before pouring.

Common flask sizes for the school foundry are:

10 inches by 10 inches × 4 over 4

10 inches by 12 inches × 4 over 4

12 inches by 14 inches × 4 over 4

12 inches by 18 inches × 4 over 4

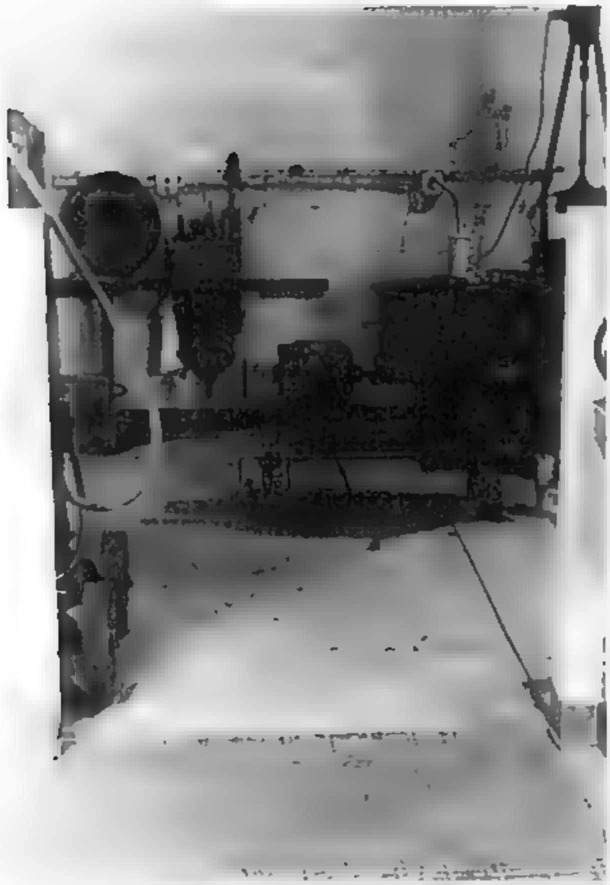


Figure 5-13
When separate foundry areas exist you can have "open" molding stations. Molding bench and tool supports are movable, which provides for flexibility and easier cleanup. Sand can be piled on the floor, but a cart simplifies transporting sand from muller, retards moisture loss, and promotes cleanliness. Floor grate at entrance to separate foundry area helps prevent contaminants from being carried into the foundry area or foundry sand being carried out.

NOTE: 4 over 4 is a designation that means 4-inch cope and 4-inch drag.

Molding and Bottom Boards

Although they can look alike, there is a distinction between *molding* and *bottom boards.* A molding board is used to support an unmounted pattern when the metalcaster is starting to ram up a mold. Such a board should extend about one inch (25 millimeters) on each side of the flask and fit with about ¼-inch (6-millimeter) clearance between the pins of the drag (Fig. 5-16).

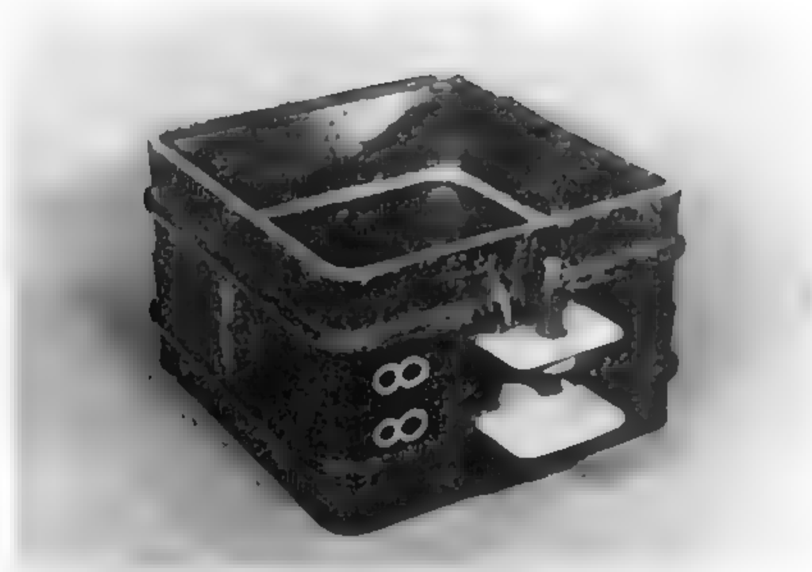


Figure 5-14
A 10-inch by 10-inch steel flask with numbers and color coding to ensure correct "mate" and better fit.

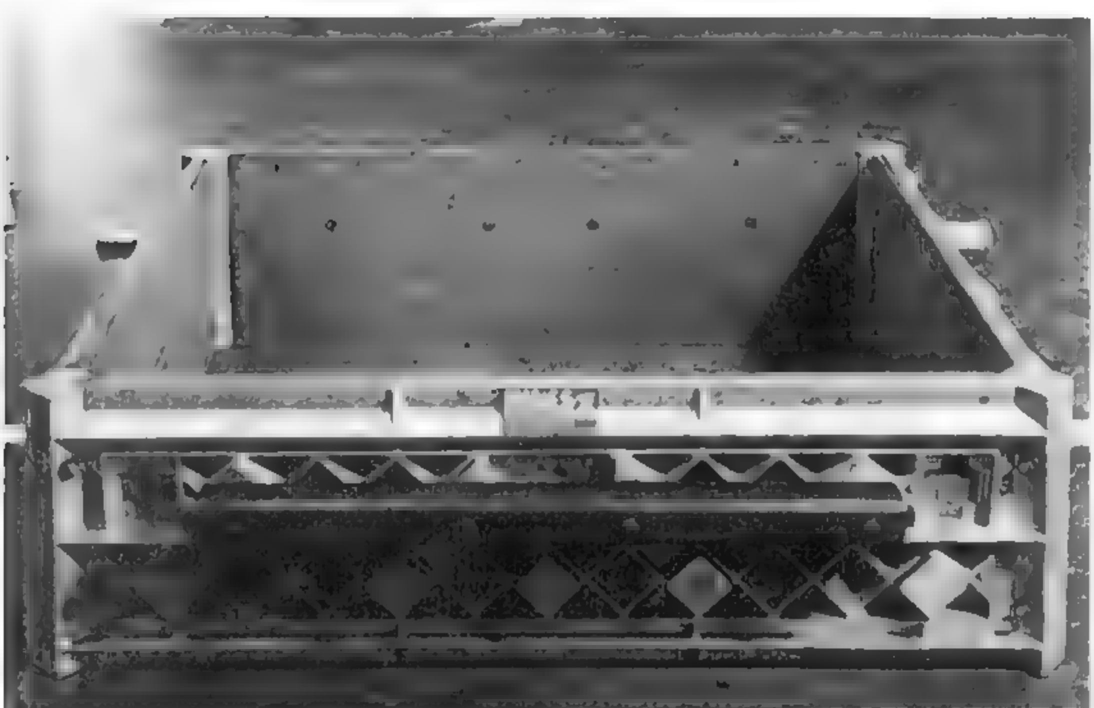


Figure 5-15
Mold jacket, which is placed on the completed mold before pouring. It supports the sand and covers the parting line of the mold.

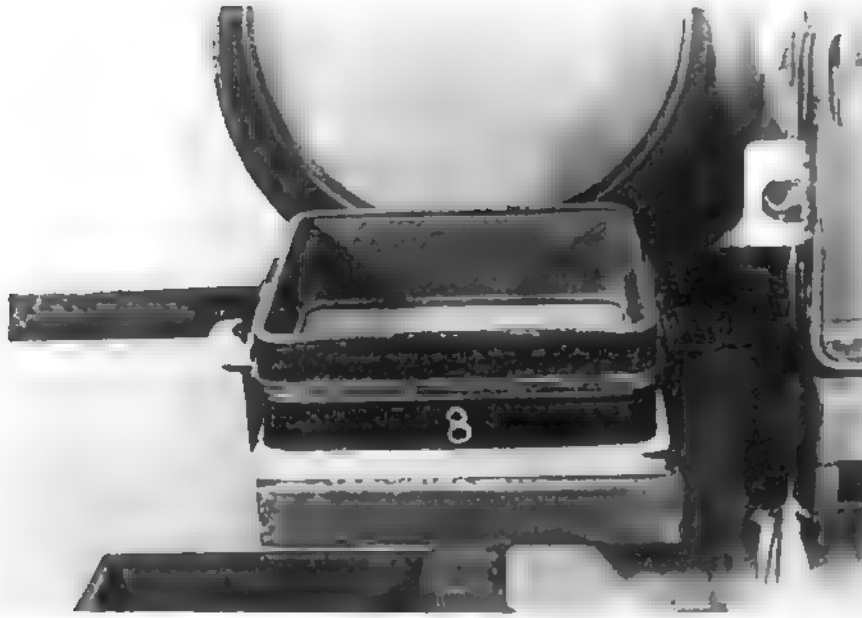


Figure 5-16
The molding board extends beyond the edge of the flask and fits between the pins of the drag.

After the drag is made up, a bottom board (Fig. 5-17) is placed on the drag and the molding board, drag, and bottom board are rolled over as a unit. The bottom board remains in this position under the mold until shakeout. A bottom board could be slightly larger than a molding board and might have ⅜-inch (10-millimeter) perforations on 1- to 2-inch centers for venting.

Both molding and bottom boards sometimes have wooden cleats securely fastened to the bottom.

In industry, bottom boards are often of cast aluminum. In a school foundry, ¾-inch plywood serves very satisfactorily for bottom and molding boards. They can be the same size and without cleats, which simplifies storage. Perforations in the bottom board are unnecessary for small flasks. Cleat-sized pieces of wood kept in the pouring area can be placed under the bottom board so the completed mold can be set on the pouring floor gently without pinching fingers (Fig. 5-18). A pouring stand eliminates the need for cleated boards or separate cleats and supports the mold at a height that makes accurate pouring easier.

Patterns

Patterns can be thought of as special foundry tools essential in the production of castings. They are usually made of wood, metals, or plastics,

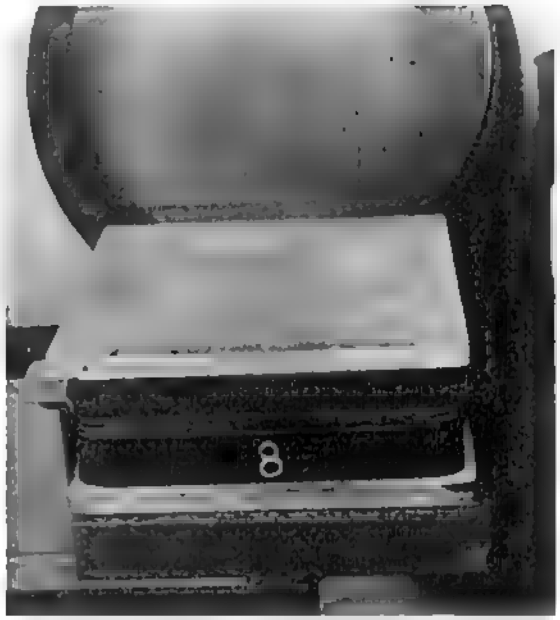


Figure 5-17
Bottom board placed on drag prior to rolling drag over. Molding boards and bottom boards can be plywood of identical size and design.

but patterns of glass, ceramic, plaster of paris, wax, or any other solid material could be used if durable enough to withstand the ramming. Many household articles, such as pans, trivets, ashtrays, and ice cream scoops, can be used as patterns. The edges of a pattern should slant inward to permit it to be drawn cleanly from the sand mold. Such slant is called **draft.**

Figure 5-18
Using separate cleats to provide desirable finger clearance when setting a completed mold on the pouring floor.

Figure 5-19
Loose patterns, typical of those used in many school foundries.

Loose (Unmounted) Patterns: **Loose patterns** are used quite a bit in school foundries. They are seldom used in industry except for experimental work or for producing a limited number of large castings (Fig. 5-19).

Matchplates: A **matchplate** consists of the pattern and most of the gating system fastened to a plate or board. The matchplate has holes (or a hole and a slot) that enable it to slip over the pins of the drag (Fig. 5-20). Most castings in industry are made in molds formed from matchplates. Matchplates increase production and accuracy. Molds can be made faster when gating systems do not have to be cut by hand. Castings are more consistent in size and metal quality when gating systems are identical, and the matchplate is vibrated rather than being rapped by hand as is done prior to pulling loose patterns.

Supplementary Molding Material and Devices

Parting Agents: Parting agents prevent sand from sticking to the pattern or to other sand at the parting line. Some are dry, finely ground waterproof minerals, and others are liquids of hard, smooth waxes in solvent bases. Liquid parting agents, which lend themselves to use with metal matchplates, are commonly used in connection with machine molding in production foundries. Dry parting compounds, which are still used to some extent in foundries, are the main type of parting agent used in school foundries. They are commonly dispensed from a cloth bag.

Parting agents should be used sparingly. Too much parting material will produce a casting with rough surface finish.

Figure 5-20
The drag side of a matchplate containing five patterns, a sprue base, and a stepped-down runner with a small (inadequate) runner extension. The two large holes fit over the pins of the drag. The small hole is for attaching a vibrator.

Chills:. Metal devices that are put in a mold to promote directional solidification are known as **chills.** External chills are specially shaped pieces of metal that are placed next to the pattern and become a part of the mold wall (Fig. 5-21). Such pieces are often coated on the surface(s) that come into contact with the molten metal. The coating prevents the molten metal from sticking to the chill. Internal chills in a wide variety of shapes are also available (Fig. 5-22). They are placed in the mold cavity

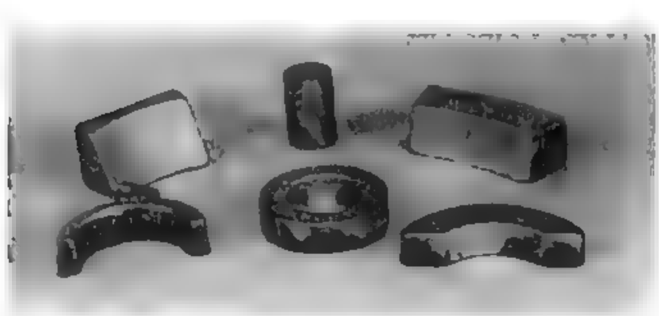


Figure 5-21
External chills are specially shaped pieces of metal that are placed in a mold and become a part of the mold wall. The surface of the chill that remains exposed to the molten metal is coated to prevent the casting from sticking to the chill.

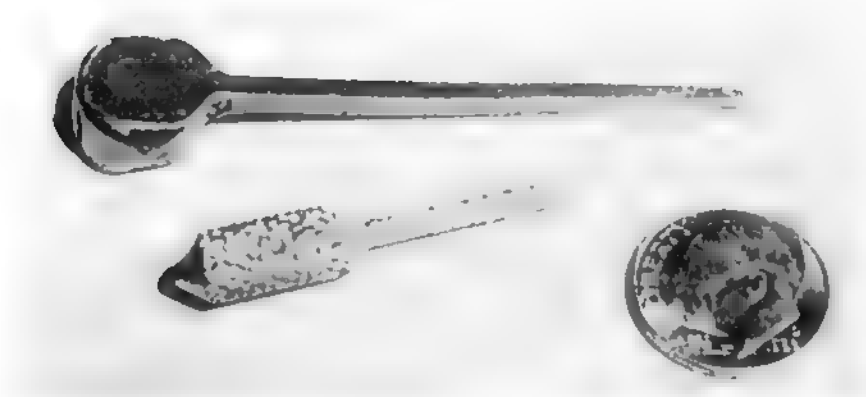


Figure 5-22
Internal chills—the sharp end is pushed into the mold wall so that the heavy head of the chill is where rapid solidification needs to occur.

before closing the mold. Most are designed to be anchored in place by pushing their ends into the mold, leaving 80–90 percent of the mass of the chill to be surrounded by molten metal. The composition of an internal chill must be compatible with the metal that is poured. Even so, such chills are frequently "entrapped" by the molten metal rather than being fused completely. This usually results in a loss of strength at this point in the casting.

Extra care is required in using chills. They must be dry and free of rust, and they should not stand in a mold so long that moisture condenses on them. Such factors, over the years, have limited the use of chills to problematic castings. The speed of today's production molding methods has further reduced the use of chills.

Foundry Nails: **Foundry nails** are made in a wide variety of sizes and shapes. The most common type looks like a carpentry nail except that the shank is slimmer and the head is smaller. They are pushed into the mold where experience has shown the sand needs additional strength. The head also provides a chilling surface and these nails as well as the heavier-headed horse-shoe type nails are used also as chills.

TOOLS USED IN MAKING SAND MOLDS

Riddle

The size of a riddle is based on its diameter and the size of the openings in the wire screen. The screen is commonly hot-dipped, galvanized steel wire, or the more expensive electrically galvanized steel or brass wire.

Common diameters are 16 inches and 18 inches. The mesh size of the screen in riddles is based on the number of openings per *linear* inch.

Appropriate mesh sizes for riddling facing sand (the thin layer of sand lying against the pattern) are 8–16 per inch, depending on the sand grain size and whether water-base or oil-tempered sands are used. Screens with larger mesh sizes, such as 4 and 2, are useful for conditioning sand in gyratory riddles.

Plastic-framed riddles are initially more expensive, but they are safer (they have no splinters) and more durable than wood-framed riddles (Fig. 5-23).

Bench Rammer

In school foundries, wooden hand rammers of maple or hickory (Fig. 5-24) are usually used to ram up molds. The wedge-shaped peen end is used to pack sand tightly against the sides of the flask and lightly over the pattern. The moldmaker continues using the rammer to pack sand as more sand is added to the flask, using the flat-faced butt end to "finish ram" all over. Metal rammers of a somewhat similar design and wedge-shaped shovel handles are sometimes used when hand ramming is done in industry. Pneumatic rammers with interchangeable wedge and butt ends are most often used in this setting.

Figure 5-23
A No. 8 mesh plastic riddle.

Figure 5-24
A bench or hand rammer of maple or hickory.

Strike-off Bar

The strike-off bar is a straight-edged piece of wood or metal. It is used to remove surplus sand from a flask, leaving a flat sand surface. A hole in one or both ends is useful for hanging the bar up when not in use.

Vent Rod

The vent rod is used to make vent holes in the cope above the pattern or at the parting line of the mold. The rod, usually about ⅛ inch (3 millimeters) in diameter, should be straight and pointed at the working end. An eye provides for better gripping of the handle end.

Sprue Cutters or Pins

Sprue holes are most commonly made with tapered **sprue cutters.** Substantial research has shown that a tapered hole can be filled better by a stream of molten metal than one that is cylindrical. A filled sprue hole causes the metal to enter the gating system with less turbulence and aspiration of air than one which is only partially full. Using a proper size sprue cutter is important. Most school foundry molds can be poured through sprues made with a ½-inch diameter by ¾-inch diameter by 7-inch length sprue cutter. Extra large molds may require a ⅝-inch diameter by ⅞-inch diameter by 7-inch length sprue cutter. A sprue pin can be used rather than a sprue cutter. Sprue pins are made of wood to the above dimensions and turned on the lathe or cut square or rectangular in cross section (Fig. 5-25). The latter style is not used extensively, but research conducted by the American Foundrymen's Society has proved it more effective because it tends to prevent vortexing of the molten metal stream as it runs down the sprue.

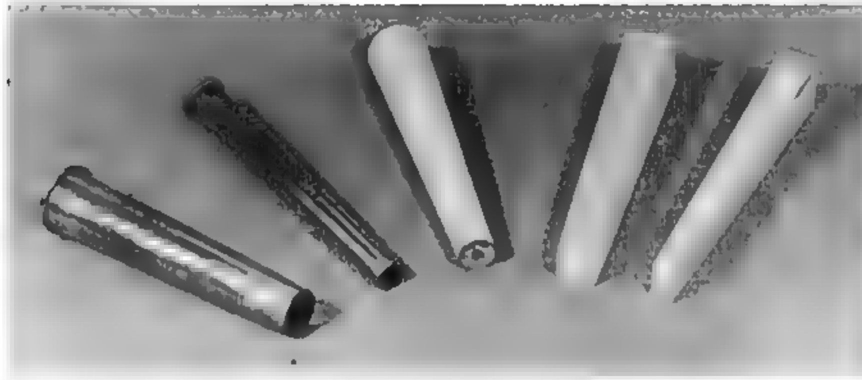


Figure 5-25
Tapered sprue cutters and pins. The solid rectangular pin on the right (little used in industry) provides the most effective shape for a downsprue.

Cylindrical Riser Cutters and Pins

The foundry should have a selection of different sized cylindrical riser cutters or pins (Fig. 5-26). Sizes less than ¾ inches (19 millimeters) are not very useful for forming risers, but can be used to make vents or flowoffs. Metal tubing of various sizes from lavatory or sink drain systems can be used as riser cutters. Short lengths of birch dowel rods of an appropriate diameter can be used as vent or riser pins. Larger pins can be turned on a lathe.

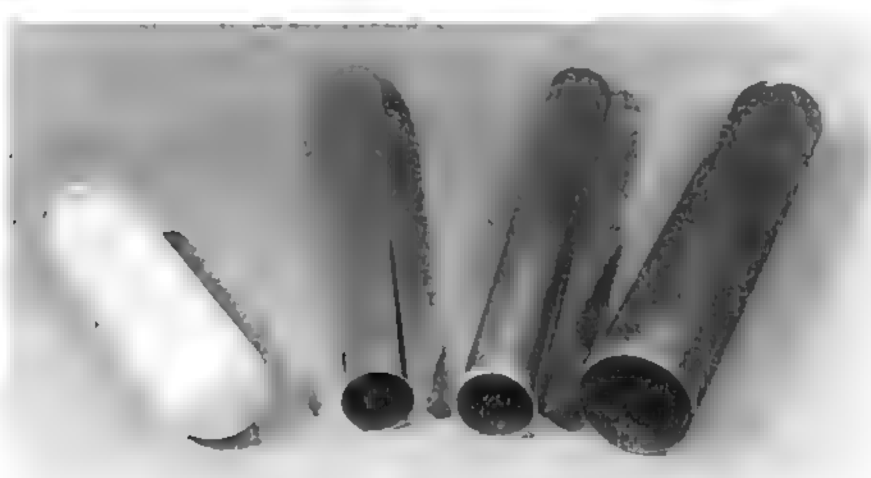


Figure 5-26
Riser cutters or pins. The two middle cutters are lengths of tubing from lavatory or kitchen drain systems.

Air or Electric Vibrators

Vibrators reduce friction and facilitate removal of a matchplate from the sand. Their use is a common industrial practice that can easily be incorporated into the school foundry. If compressed air is available, small Vibrolators are most useful (Fig. 5-27); if not, small electric vibrators are available. One vibrator adapted with a special quick clamp (Fig. 5-28) can serve a number of molding stations.

Draw Spikes, Draw Screws and Other Temporary Handles

Temporary handles are needed to draw loose patterns from the sand. With wooden patterns, a **draw spike** is tapped into the back of the pattern until the spike has enough gripping power so that it can be rapped in all directions and lifted without losing its hold on the pattern. A **draw screw**

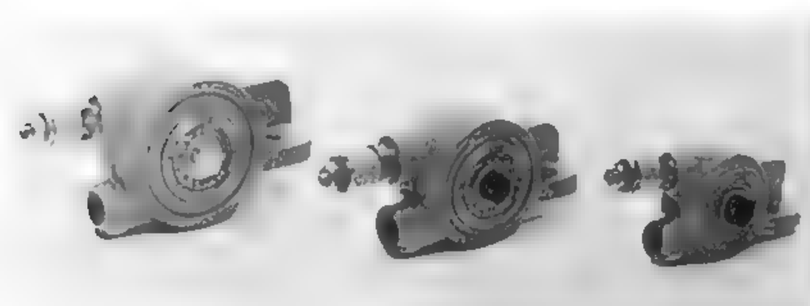


Figure 5-27
Compressed-air vibrolators are available in sizes appropriate for use with the small matchplates used in school foundries.

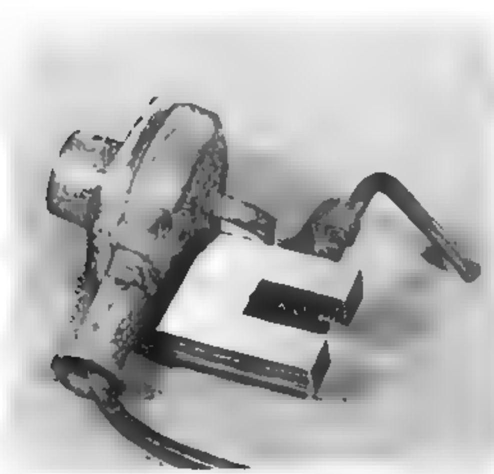


Figure 5-28
A shop-made quick clamp that makes it easier for one electric vibrator to serve several molding stations.

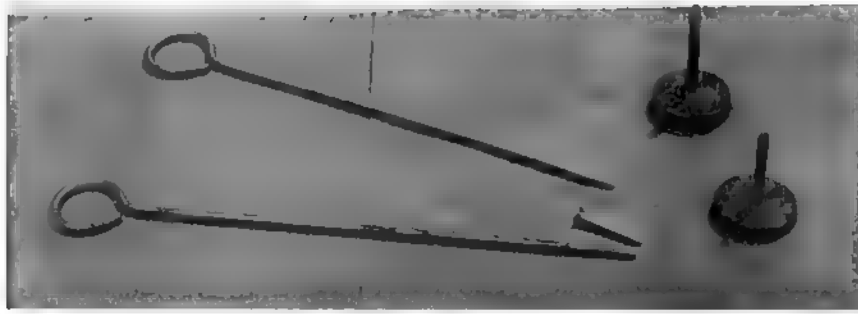


Figure 5-29
Shop-made draw spikes and draw screws.

(with a wood-screw type thread) provides a somewhat more positive means of gripping a wooden pattern. With metal or plastic patterns, the patterns are drilled and tapped for use with a draw screw with machine-screw type threads. Draw spikes and draw screws can be made (Fig. 5-29). Patterns with flat surfaces can be drawn by means of a rubber suction cup.

Rapping Bar

A rapping bar is required *only* for loose-pattern work. The design of the rapping bar is not critical. An 8-inch (200-millimeter) length of ½-inch rod will serve. Regardless of its shape, it is important to have a specific tool for rapping loose patterns and a specific place for it to be stored.

Bulb Sponge

A **bulb sponge** is required *only* for loose-pattern work with natural bonded or synthetic sand that is *conditioned with water* (Fig. 5-30). (Do not use a bulb sponge with oil-tempered (waterless) synthetic sand.) The bulb is filled with water and a small amount of pressure enables one to add a *slight amount* of moisture around the pattern just before rapping and pulling a loose pattern.

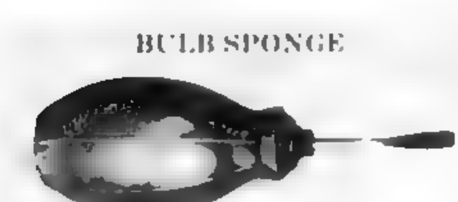


Figure 5-30
The bulb sponge is used to moisten water-base sand around loose patterns. *Do not use water* with oil-base sand.

Figure 5-31
This air gun meets OSHA standards in providing compressed air at a maximum of 30 pounds per square inch.

Bellows or Low-Pressure Air Line

Traditionally, the molder used a bellows to remove loose sand before closing the mold. Modern molders use air guns for this purpose (Fig. 5-31). **OSHA** regulations require that all compressed air coming from lines be reduced to a maximum of 30 psi. This much pressure used carelessly can damage a mold. If compressed air is available and you feel sure you can use it with sufficient care, do so. If not, use a **bellows.**

Finishing Trowel (Round Point)

Trowels are used mostly when working with loose patterns. They come in several different shapes. Student molders seem to have more success with round point trowels (Fig. 5-32).

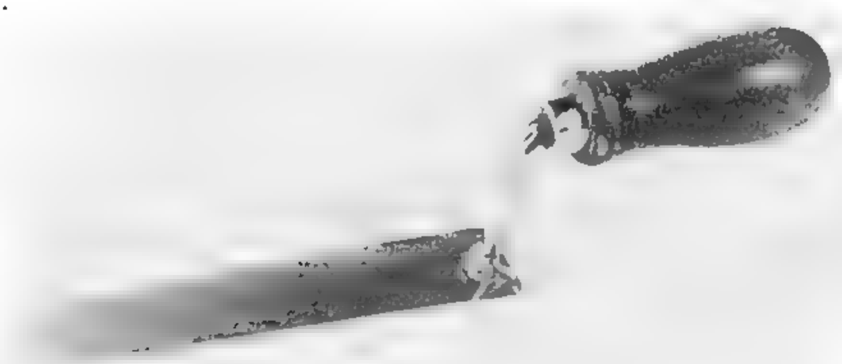


Figure 5-32
Molder's finishing trowel—useful for smoothing parting surfaces.

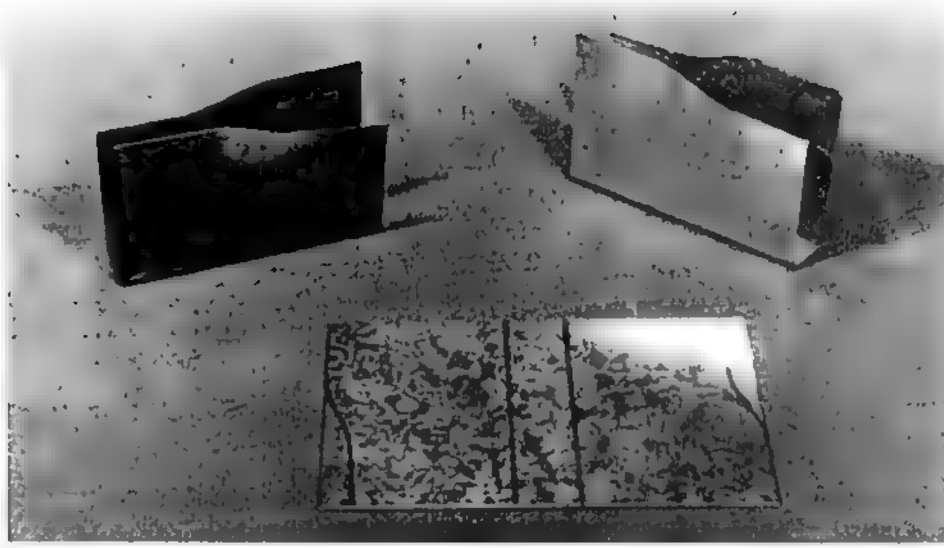


Figure 5-33
Gate cutters—a commercially made brass gate cutter (*left*) and a shop-made one of galvanized steel.

Gate Cutter

Gate cutters are required *only* for loose pattern work. Brass gate cutters are available from foundry or school shop suppliers. Suitable gate cutters can be made of galvanized sheet metal (Fig. 5-33).

Molders Tools

Molder's tools of various shapes, useful for repairing molds, are commercially available. One each of the following will meet most needs:

- 1-inch slick and oval
- ¾-inch slick and square
- ¼-inch by 12-inch lifter

These tools are most useful with loose-pattern work and have limited application when molding with matchplates.

Mold Spray Equipment

Spray cans filled with a proprietary mold spray are used with an air gun.

MOLDING

Green sand molds are produced in a number of ways. Three common procedures are shown in this section. The first procedure described is molding with a loose pattern. Figures 5-LP-1 through 5-LP-18 illustrate loose-pattern molding. The second procedure described in this section is molding at the bench with a matchplate. The description of the matchplate molding process is illustrated in Figures 5-MP-1 through 5-MP-11. The final procedure described in this section is molding with a jolt-squeeze machine; refer to Figures 5-JS-1 through 5-JS-7.

Loose Pattern Molding

Loose or unmounted patterns are seldom used in industry except for producing prototype castings or very large castings of very limited numbers. Loose patterns are, however, appropriate for learning basic molding procedure and are much used in school foundries. The following procedure utilizes a flatback pattern.

1. Condition the sand. Natural or water-base synthetic sand is moistened with water and mulled or mixed until a squeezed handful will support itself when held near one end (Fig. 5-LP-1) and break with sharp corners (Fig. 5-LP-2). *Do not moisten oil-tempered (waterless) foundry sand;* instead, condition by mulling if possible.
2. Place molding board on bench.
3. Place drag with pins down on molding board.
4. Place pattern in the drag with draft up and *off to one side* to allow room for the gating system (Fig. 5-LP-3).
5. Shake a very light coating of parting compound over the pattern.
6. Riddle a 1-inch layer of facing sand (Fig. 5-LP-4).
7. Tuck and pack sand around the pattern with fingers.
8. Fill drag with "heap sand" (unriddled sand from the heap).
9. Peen-ram against sides of drag and lightly over pattern (Fig. 5-LP-5).
10. Shovel heap sand in drag to overflowing.
11. Butt-ram hard around edges of drag but reduce ramming force over pattern.
12. Strike off surplus sand with a straight edge (Fig. 5-LP-6).

13. Sprinkle sand over drag.
14. Place bottom board on drag and rub board for good tight "seat."
15. Roll molding board, drag, and bottom board over as a unit.
16. Remove molding board and smooth the parting, if necessary, with trowel or slick.
17. Place cope half of flask on drag.
18. Mark the position of the pattern with coordinate chalk marks on the sides of the flask so that the sprue can be made with a sprue cutter in the proper position at a later time (Fig. 5-LP-7).
19. Repeat steps 5 to 12 above, with the cope instead of the drag.
20. Vent cope over the pattern with venting wire; punch holes to within ¼ inch (6 millimeters) of pattern (Fig. 5-LP-8). Holes should be 1–2 inches (26–52 millimeters) apart.
21. Locate the sprue and cut a sprue hole ½ inch (13 millimeters) deeper than the parting line (Fig. 5-LP-9). Use a round tapered sprue cutter. Any other necessary holes should be cut at this time.
22. Cut pouring basin for sprue hole (Fig. 5-LP-10)—unless a pouring basin of core sand is to be used.
23. Clean sand from around flask pins with an air gun or bellows.
24. Lift off cope and set aside (Fig. 5-LP-11).
25. Make a base at the bottom of the sprue hole and cut a runner and a runner extension of the appropriate size in the drag (Fig. 5-LP-12).
26. Cut one or more gates in the cope (Fig. 5-LP-13).
27. Swab around the pattern with a bulb sponge (Fig. 5-LP-14).

CAUTION: Do not get sand too wet.

28. Insert draw screws and/or draw spikes as needed—rap in all directions (Fig. 5-LP-15).
29. Pull pattern and set it aside (Fig. 5-LP-16).
30. Check mold cavity and gating system for loose sand and remove any that exists with bellows or air gun.
31. Spray mold cavity and gating system with mold spray (Fig. 5-LP-17).
32. Set any cores that are required.
33. Place cope on drag.

34. Place bottom board and flask on pouring stand or floor.
35. Clamp or weight the flask (Fig. 5-LP-18).
36. Place pouring basin made of core sand above sprue hole (unless one has been cut along side of the sprue).

For the rest of the process, see the Melting and Pouring Sequence in Chapter 6.

Figure 5-LP-1
A squeezed handful of properly conditioned foundry sand should retain finger imprints and support itself when held by one end.

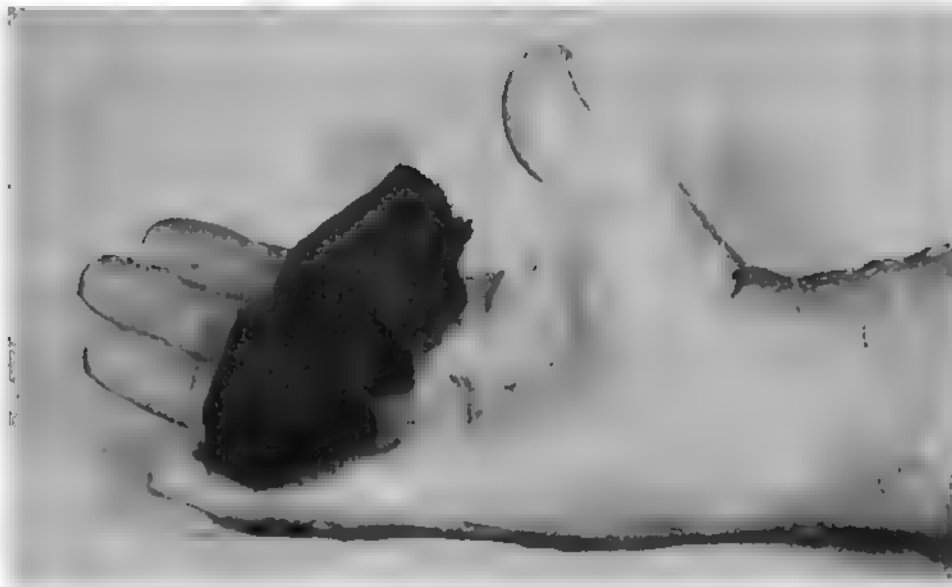


Figure 5-LP-2
Properly conditioned sand will break with sharp corners.

Figure 5-LP-3
Place pattern, draft up, on molding board, to one side of the center.

Figure 5-LP-4
Facing sand—that which lies against the pattern—should be riddled.

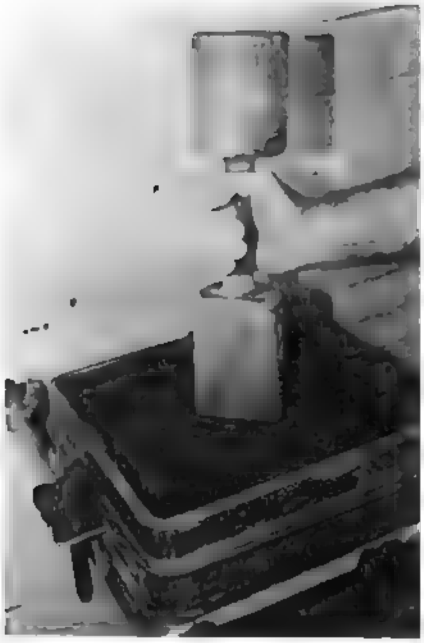


Figure 5-LP-5
Ram sand tight against sides of drag with peen end of rammer and then lightly over the pattern.

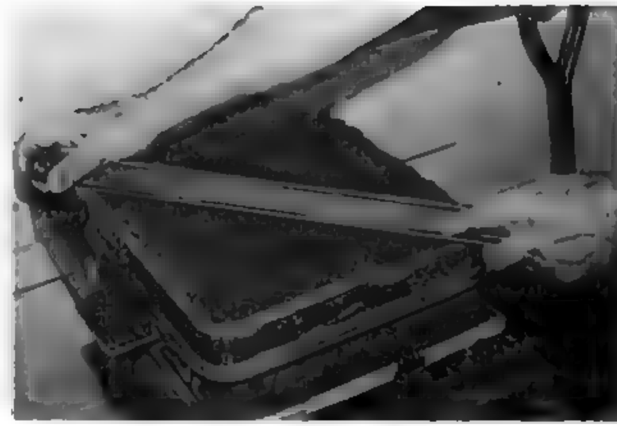


Figure 5-LP-6
Strike off surplus sand.

Figure 5-LP-7
Chalk reference marks on one side and end of the flask to aid in properly locating the sprue which will be cut later. If a sprue pin were being used, it should be located in an appropriate place and tapped about 1" (26 mm) into the sand of the drag so it will be self-standing.

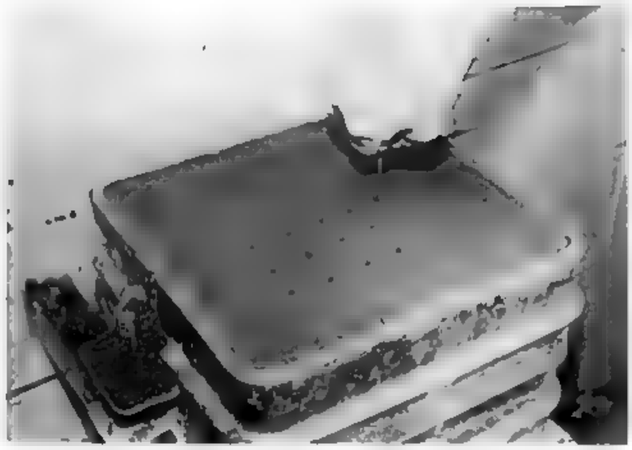


Figure 5-LP-8
Vent cope over pattern, punching holes to within ¼ inch (6 millimeters) of the pattern.

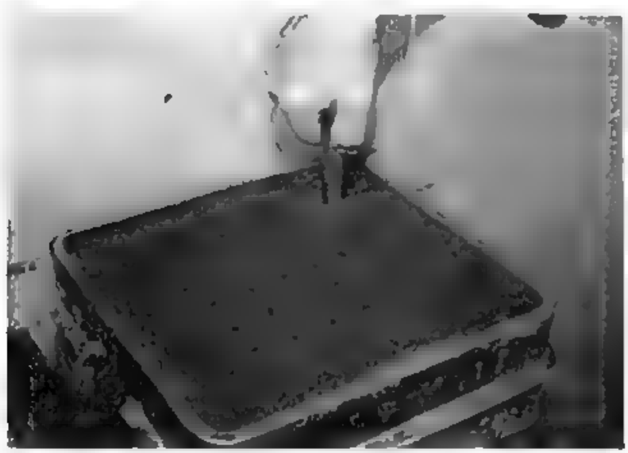


Figure 5-LP-9
Locate the sprue and cut a sprue hole to approximately ½ inch (13 millimeters) deeper than the parting line.

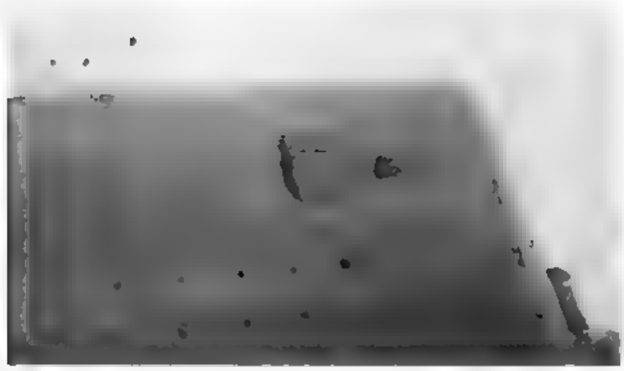


Figure 5-LP-10
Cut a pouring basin beside the sprue. (The sprue cutter or sprue pin should not be removed until the basin is complete.) The basin should be flat-bottomed and large enough to hit easily with a stream of molten metal. Construct the basin with a dam about ½ inch (13 millimeters) high so that the molten metal should have to rise to that height before it flows down the sprue. It is much easier and less time-consuming to *place* a pouring basin made of core sand over the sprue than to *cut* one alongside the sprue.

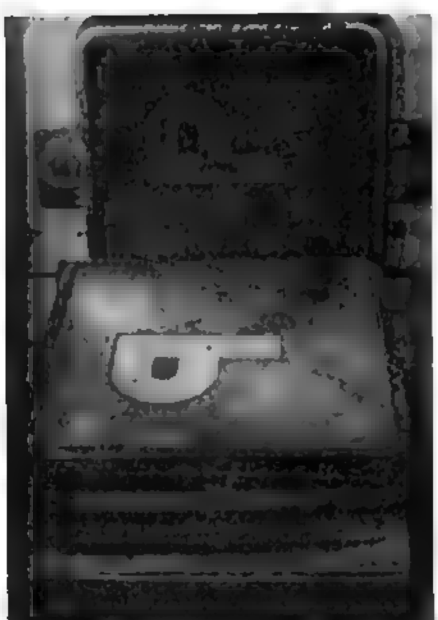


Figure 5-LP-11
Lift off cope and set aside. Always check to see that the sprue is open.

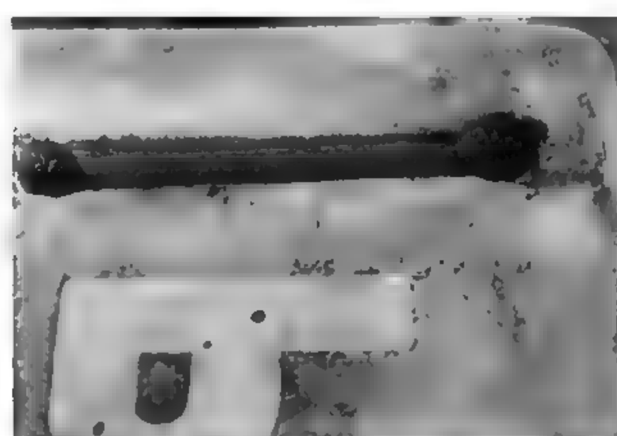


Figure 5-LP-12
Cut sprue base (*upper right*), tapered runner, and runner extension (sump) in the drag.

Figure 5-LP-13
Cut gates (that will overlap the runner somewhat) in the cope.

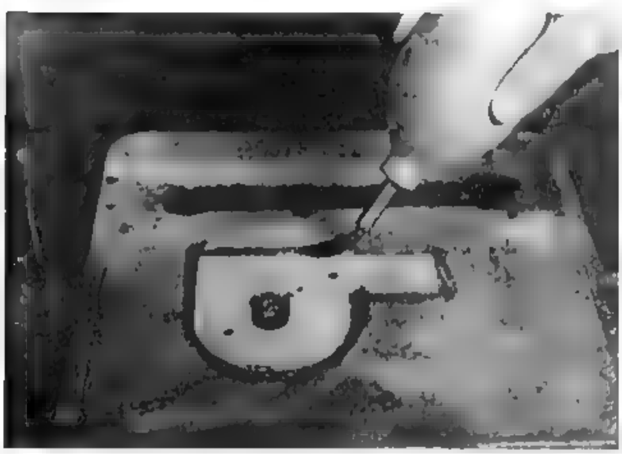


Figure 5-LP-14
Swab around the pattern with a bulb sponge. This, of course, is *not* done if oil-tempered (waterless) foundry sand is being used.

Figure 5-LP-15
Insert draw screws or spikes into the pattern (or attach some other kind of a temporary handle to the pattern) and rap in all directions to loosen the pattern in the mold.

Figure 5-LP-16
Pull the pattern and set it aside.

Figure 5-LP-17
Use spray can and air gun to apply mold spray to the mold cavity and gating system of cope and drag.

Figure 5-LP-18
The flask should be clamped (gently) or weighted to prevent runouts at the parting line.

Matchplate Molding

Matchplates improve the efficiency of the molding process. Patterns mounted on a plate are much easier to remove from the sand than loose patterns. Vibrating a matchplate produces castings that are much more consistent in size than loose patterns, which are rapped, sometimes harder than at other times. In most instances, the sprue base, runner, runner extension or sump, and gates are a part of the matchplate. This eliminates the need to cut these by hand. The following procedure uses a matchplate that is the most common pattern used in industrial foundries. Although a production flask would be helpful, it is not essential. The use of a vibrator is strongly recommended as is that of a pouring basin produced from core sand.

1. Condition the sand. Natural or water-base synthetic sand is moistened with water and mulled or mixed until a squeezed handful will support itself when held near one end and break with sharp corners. *Do not moisten oil-tempered (waterless) foundry sand;* instead, condition by mulling if possible.
2. Assemble matchplate between cope and drag as follows:
   - Cope on molding bench with the bushings up (Fig. 5-MP-1)
   - Matchplate aligned over cope with sprue base up (Fig. 5-MP-2)
   - Drag with pins going through holes in matchplate and through bushings of cope (Fig. 5-MP-3)
3. Use chalk to mark the location of the sprue base on one side and end of the flask (Fig. 5-MP-4).
4. Shake a very light coating of parting compound over the matchplate.
5. Riddle a 1-inch (25-millimeter) layer of facing sand.
6. Tuck and pack sand around pattern with fingers.
7. Fill drag with "heap sand."
8. Peen-ram sand against sides of drag and lightly over pattern.
9. Shovel heap sand in drag to overflowing.
10. Butt-ram hard around edges of drag; reduce ramming force over pattern.
11. Strike off surplus sand with a straight edge.
12. Sprinkle sand over drag.
13. Place bottom board on drag and rub board for good tight seat.

14. Roll cope, matchplate, drag, and bottom board over as a unit (Fig. 5-MP-5).
15. Repeat steps 4 through 11 above with the cope.
16. Vent cope over pattern with venting wire. Punch holes to within ¼ inch (6 millimeters) of pattern. Holes should be 1–2 inches apart.
17. Clean sand from around flask pins with an air hose or bellows.
18. Locate and cut sprue down to the matchplate. Be sure to use a tapered sprue cutter. Also, cut holes for any necessary open risers at this time.
19. Attach vibrator to matchplate (Fig. 5-MP-6).
20. Vibrate and remove cope (Fig. 5-MP-7).
21. Vibrate and remove matchplate (Fig. 5-MP-8).
22. Make **whisker vents** and cut **whistler (flow off)** from the runner extension or sump through the cope if permeability of mold is in doubt (Fig. 5-MP-9).
23. Check mold cavity and gating system and remove any loose sand with a bellows or air hose (Fig. 5-MP-10).
24. Spray mold cavity and gating system with mold spray.
25. Set any cores that are required.
26. Place cope on drag (Fig. 5-MP-11).
27. Place bottom board and flask on pouring stand or floor.
28. Clamp or weight the flask.
29. Place pouring basin (made of core sand) above sprue hole (Fig. 5-MP-12).

For the rest of the process, see the Melting and Pouring Sequence in Chapter 6.

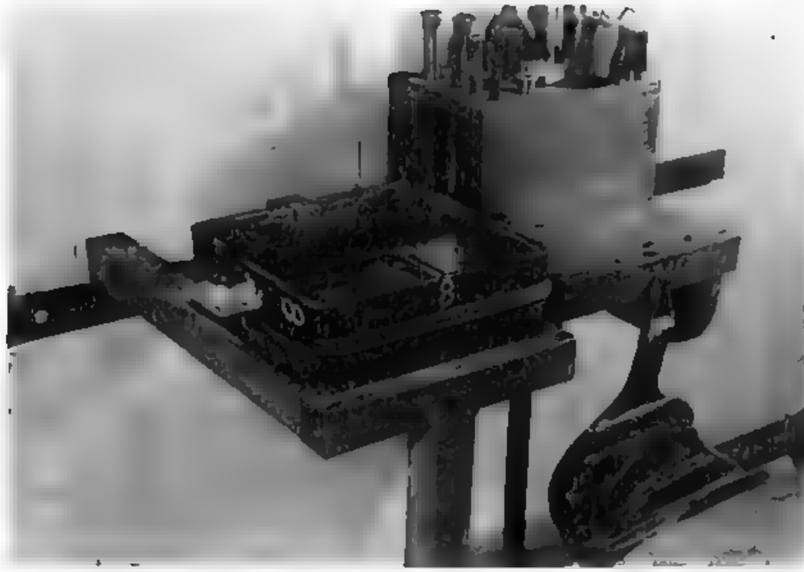


Figure 5-MP-1
To position a matchplate properly between the cope and drag, place *cope* on bench with bushings *up*.

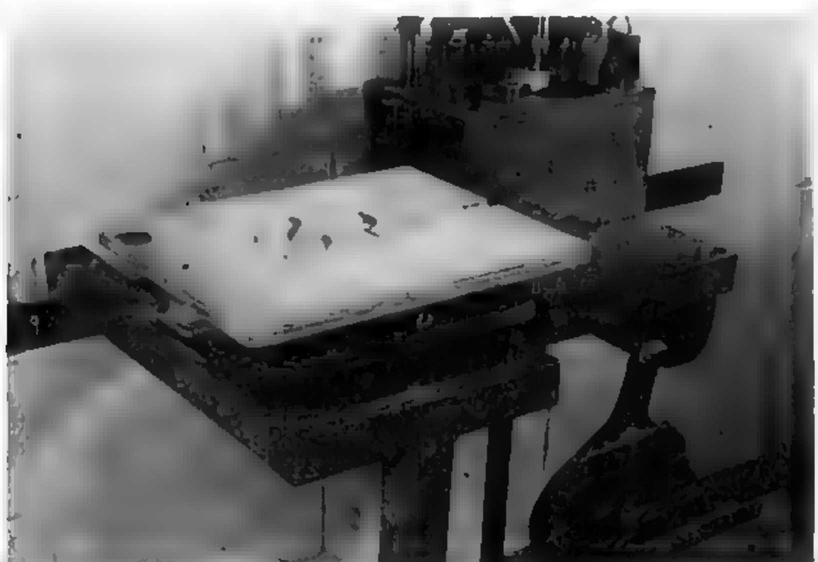


Figure 5-MP-2
Place matchplate on cope with sprue base up and holes in matchplate aligned with bushings of cope.

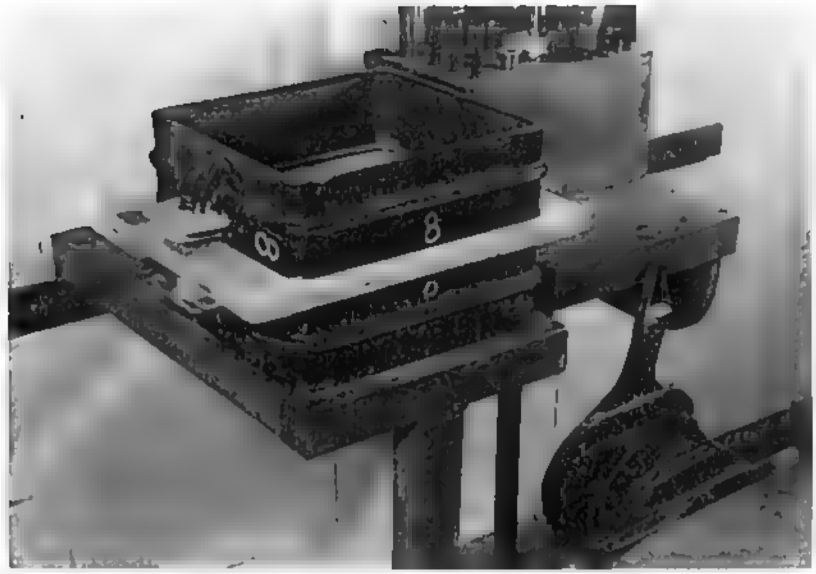


Figure 5-MP-3
Install drag on matchplate with pins of drag inserted through matchplate and bushing holes of cope. Be sure the color codings on flask ends match.

Figure 5-MP-4
Chalk reference marks on one side and end of the flask for later aid in cutting sprue to line up with sprue base.

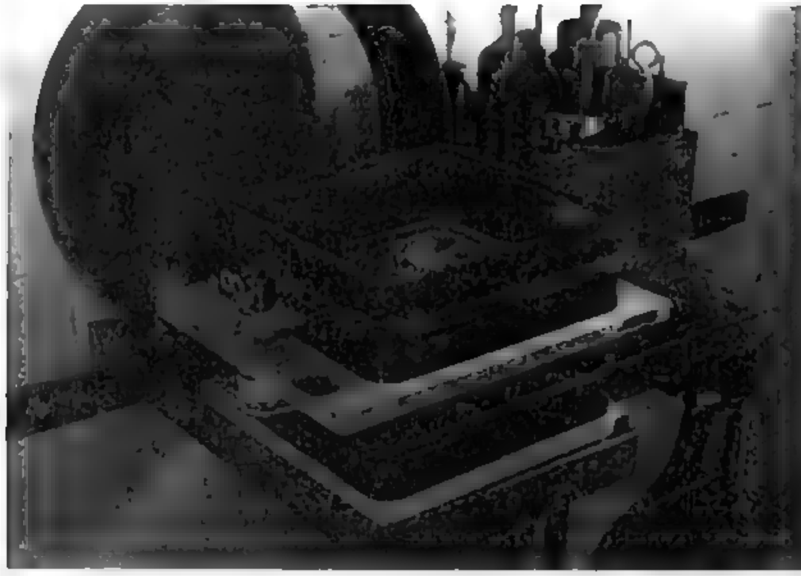


Figure 5-MP-5
Roll entire unit over so cope is on top and bottom board is under drag.

Figure 5-MP-6
Attach vibrator to matchplate. Notice use of shop-made quick clamp.

Figure 5-MP-7
Vibrate and remove cope. Always check to see that the sprue is open.

Figure 5-MP-8
Vibrate and remove matchplate.

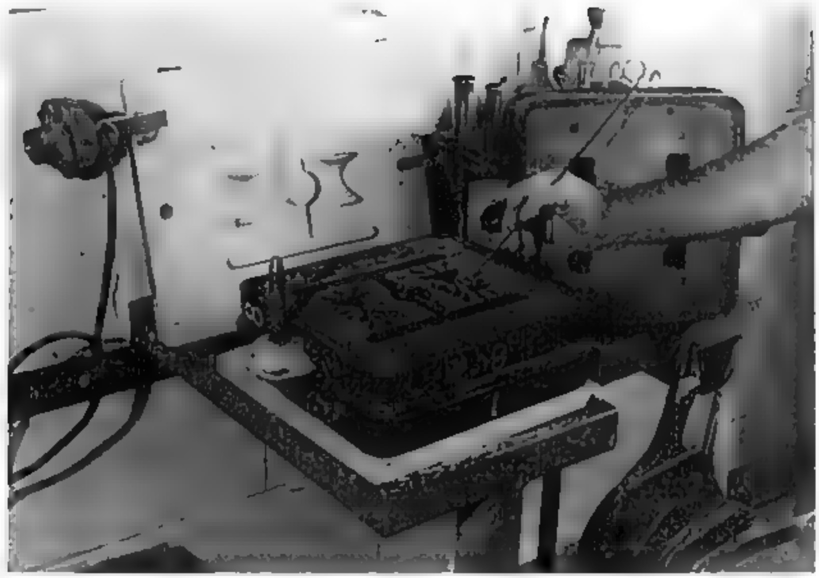


Figure 5-MP-9
Wisker vents aid in exhausting air and gasses from mold.

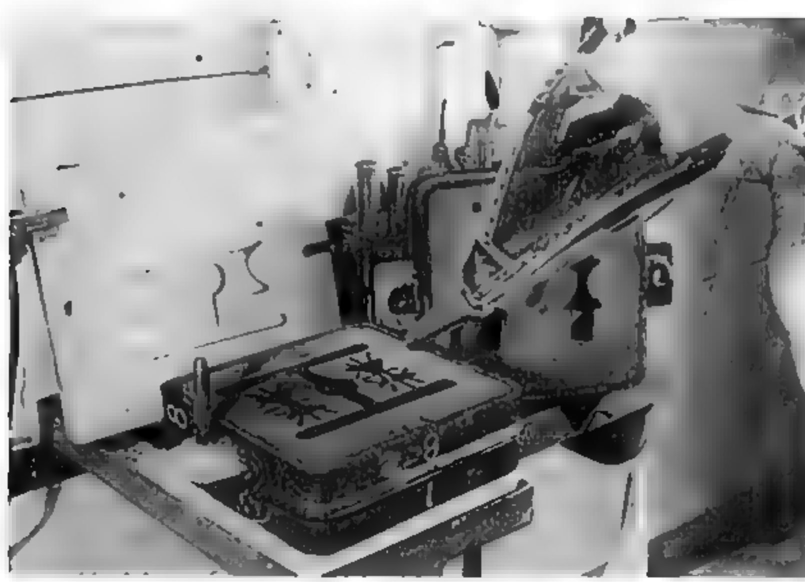


Figure 5-MP-10
It is essential that any loose sand be removed from the cavity or any part of the gating system.

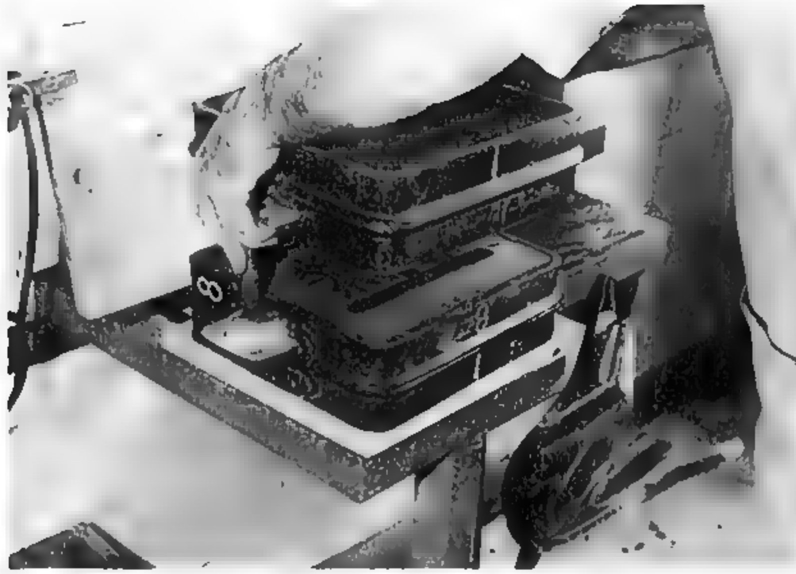


Figure 5-MP-11
Finding the pins with the fingers helps to position the cope when replacing it on the drag.

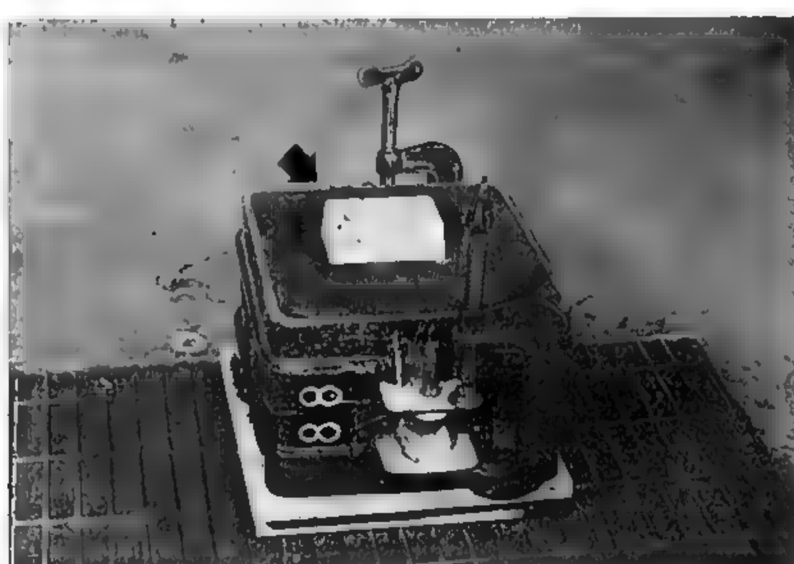


Figure 5-MP-12
The technique used in industry is to place a pouring basin (made of core sand) over the sprue hole.

Molding with Jolt-Squeeze Machines

Jolt-squeeze machines eliminate a great deal of the physical effort that is expended in molding at the bench. A matchplate must be used. The machine will pack the sand in the drag by jolting. Later, sand in both the cope and drag will be squeezed uniformly against the matchplate. Jolt-squeeze machines are powered by compressed air. Before starting,

1. Connect the machine to the nearest compressed-air outlet.
2. Attach the vibrator to the matchplate.
3. See that the squeeze head is swung to the side, leaving the space above the table empty.

The procedure for molding with a jolt-squeeze machine is as follows:

1. Condition the sand. Natural or water-base synthetic sand is moistened with water and mulled or mixed until a squeezed handful will support itself when held near one end and break with sharp corners. *Do not moisten oil-tempered (waterless) foundry sand;* instead, condition by mulling if possible.
2. Assemble matchplate between cope and drag as follows:
   - Cope on machine table with bushings up
   - Matchplate aligned over cope with sprue base up
   - Drag with pins going through holes in matchplate and through bushings of cope
3. Use chalk to mark the location of the sprue base on one side and end of the flask.
4. Shake a very light coating of parting compound over the matchplate.
5. Riddle a 1-inch (26-millimeter) layer of facing sand.
6. Fill drag with heap sand to overflowing.
7. Jolt 10 times by using right knee valve (Fig. 5-JS-1).
8. Strike off surplus sand with a straight edge.
9. Place bottom squeeze board and jolt four more times to seat board about ¼ inch (6 millimeters) deep in drag (Fig. 5-JS-2).
10. Roll cope, matchplate, drag, and bottom board over as a unit (Fig. 5-JS-3).
11. Repeat steps 4 and 5 above.
12. Fill cope with heap sand to overflowing and ram lightly with shovel.

13. Strike off surplus sand with a straight edge.
14. Place top squeeze board (Fig. 5-JS-4).
15. Swing squeeze head over flask (Fig. 5-JS-5).
16. Squeeze by actuating two-hand safety controls; hold for 5 seconds and then release (Fig. 5-JS-6).
17. Return squeeze head to original position.
18. Remove top squeeze board.
19. Locate and cut sprue down to the matchplate. Be sure to use a tapered sprue cutter. Also, cut holes for any necessary open risers.
20. Clean sand from around flask pins with air hose or bellows.
21. Vibrate by actuating left knee valve and remove cope (Fig. 5-JS-7).
22. Vibrate and remove matchplate. Check mold cavity and gating system and remove any loose sand with a bellows or air hose.
23. Spray mold cavity and gating system with mold spray.
24. Set any cores that are required.
25. Place cope on drag.
26. Place bottom board and flask on pouring stand or floor.
27. Clamp or weight the flask.
28. Place pouring basin (made of core sand) above sprue hole.

For the rest of the process, see the Melting and Pouring Sequence in Chapter 6.

Figure 5-JS-1
Jolt 10 times, using valve operated by the right knee.

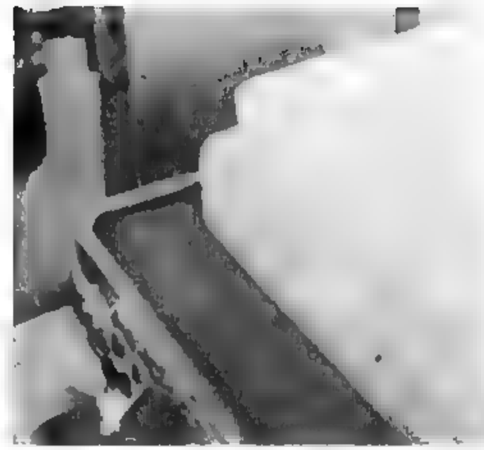


Figure 5-JS-2
Place bottom squeeze board and jolt four times to seat the board slightly inside the flask. A squeeze board is thicker than boards used for bench molding and fits *inside* the flask with about ¼-inch (6-millimeters) clearance all around.

Figure 5-JS-3
Roll entire unit over so cope is on top and squeeze board is on the bottom.

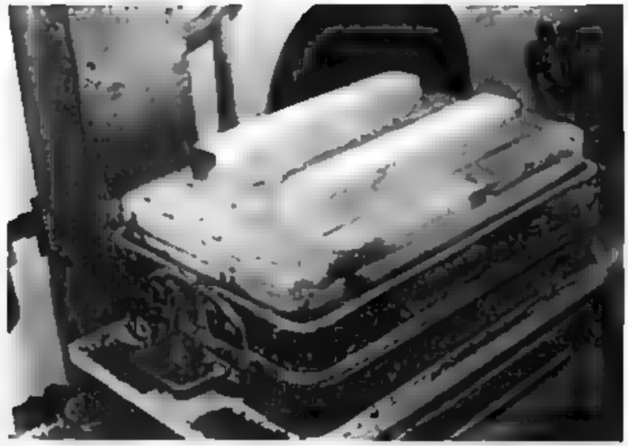


Figure 5-JS-4
Place top squeeze board.

Figure 5-JS-5
Swing squeeze head into squeeze position; adjust flask so it is directly under the squeeze head.

Figure 5-JS-6
Squeeze by pressing two-hand safety controls. *NOTE:* It is essential that a squeeze board be *below* and *above* the sand in the flask so that squeeze pressure is applied equally to both sides of the matchplate; otherwise, the tremendous pressure will damage the matchplate.

Figure 5-JS-7
Vibrate by pressing left knee valve and remove cope. Always check to see that the sprue is open.

TEST YOUR KNOWLEDGE

Write your answers on a separate sheet of paper. Do not write in this book.

1. Green sand molds are made of __________ sand.
2. Most industrial foundry sands are combinations of __________ sand, clays, additives, and __________.

T-F 3. Foundry sand works best when it is newly mixed.

4. The most fundamental and inexpensive piece of sand-conditioning equipment is the __________.
5. The common foundry sand test that is most like the hand-squeeze test of an experienced molder is the __________ test.
6. Chills are metal devices that are put in a mold to promote directional __________.

T-F 7. Sand molds are sometimes strengthened with foundry nails.

T-F 8. Most flasks are rectangular, but some are round.

9. Generally, the half of the flask with pins is the lower half and is called the __________; the half with bushings is the top half and is called the __________; technically, the part of the flask that is on the bottom

when the mold is poured is the __________, whether it has pins or bushings.

10. An 8-mesh riddle has __________ openings per linear inch.

11. Riser cutters are not very useful unless they are __________ inches in diameter or larger.

12. When starting to mold a loose pattern, the moldmaker places the pattern on a __________ board surrounded with the drag and with its pins pointing __________.

13. The sand that is riddled over a pattern is called __________ sand.

T-F **14.** Risers are not always required. They should be used when some sections of the casting are heavier (thicker) than others.

15. Runners should be in the __________, gates in the cope.

16. When loose patterns are to be removed from the mold, pulling, moistening, and rapping should be done in the following order: __________, __________, and __________.

17. When a completed mold is moved from the molding area to the pouring area, it should be carried on and supported by the __________ __________.

T-F **18.** Making molds with a matchplate is more efficient than working with loose patterns.

T-F **19.** When making a mold on the jolt-squeeze machine, the moldmaker compacts the sand in the drag by jolting, then uses the squeeze mechanism to compact sand in both the cope and the drag.

CHAPTER 6

Melting and Pouring

Furnaces for Melting Metal • Crucibles • Pyrometric Equipment • Tools Used in Melting • Coating Tools Used in Melting • Tools Used in Pouring • Pouring Floor • Tool Panel for Melting and Pouring Tools • Metal • Molten Metal Treatment Products and Processes • Melting • Pouring • Shakeout • Gate Removal • Finishing

CHAPTER GOALS

After studying this chapter you should be able to:

1. Name at least two different industrial type furnaces and indicate whether they are used to melt ferrous alloys, nonferrous alloys, or both.
2. Indicate at least three rules to observe in providing proper care for a crucible furnace.
3. Tell where the liquid level should be when a crucible has been filled to its working capacity.
4. State at least five precautions that should be taken when using crucibles.
5. Tell why it is important that anything added to molten metal (charge metal, tools, and so on) be completely dry (preheated).
6. Describe how to develop a melting schedule without a pyrometer.
7. Indicate the location of safety legs on a single-end crucible shank (two-person) and point out several important reasons for their use.
8. Compare responsibilities for melting in the school foundry with those in an industrial foundry.
9. Explain why this book does not provide a procedure for melting gray iron.

TERMS TO KNOW (see Glossary)

Cupola
Slag hole
Front slagger
Slag
Wind box
Tuyeres
Flux
Charging door
Bot
Induction furnace
Coreless induction furnace
Channel induction furnace

Crucible furnace
Crucibles
Cover flux
Pyrometer
Dross
Iron pick-up
Spangles
Crucible tongs
Crucible shank
Latch bar
Ingot molds

Wrought
Cover flux
Temperature peak
Degasser
Cuprex 100
Slag coagulant
Phos-copper shot
Deoxidize
Fluidize
Runout

FURNACES FOR MELTING METAL

Various kinds of furnaces are used to change metal from a solid to a liquid state. In this section, we will discuss some of those most commonly used in foundries.

Cupola

The **cupola** has been used for many years and continues to be used to melt gray, malleable, and ductile iron. As can be seen in Figure 6-1, a conventional cupola is a hollow vertical cylinder lined with refractory material. (Water-cooled cupolas used in high-production foundries do not need refractory linings.) Its four legs enable the hinged bottom doors to drop to a vertical position. During operation, the bottom doors are closed and propped in place. A bed of sand is rammed and shaped so that it slopes toward the spout. Somewhat higher and opposite the spout is a **slag hole.** (Many cupolas in use today are **front slaggers** in which the **slag** comes out of the tap hole with the iron and the slag is separated from the iron by a specially designed spout.) Just above the slag hole is the **wind box,** which is connected to a blower. The air from the blower fills the wind box and enters the cupola through a number of openings **(tuyeres)**. Coke, pig iron, scrap metal, and limestone (to serve as a **flux**) are added through an opening in the side wall near the top of the cupola called a **charging door.**

To operate the cupola, kindling and a charge of coke are placed on the sand bed and ignited through the tap hole. Additional coke is added and sufficient air is provided until a bed of red-hot coke reaches a predetermined height above the tuyeres. The tap hole is closed with a clay plug (**bot**). Then a number of carefully proportioned charges of coke, metal, and limestone are added until the charging door is reached. The air blast is turned on. Air forced through the tuyeres burns the coke and the resulting hot gases heat the charges above, melting small drops of metal and slag, which trickle through the coke and collect in the well. As liquid metal is drawn off at the bottom (by breaking the clay bot), additional charges are added at the top. The operation can continue for periods of several hours to a week. When all the molten metal has been removed from the cupola, the air blast is turned off and the prop sup-

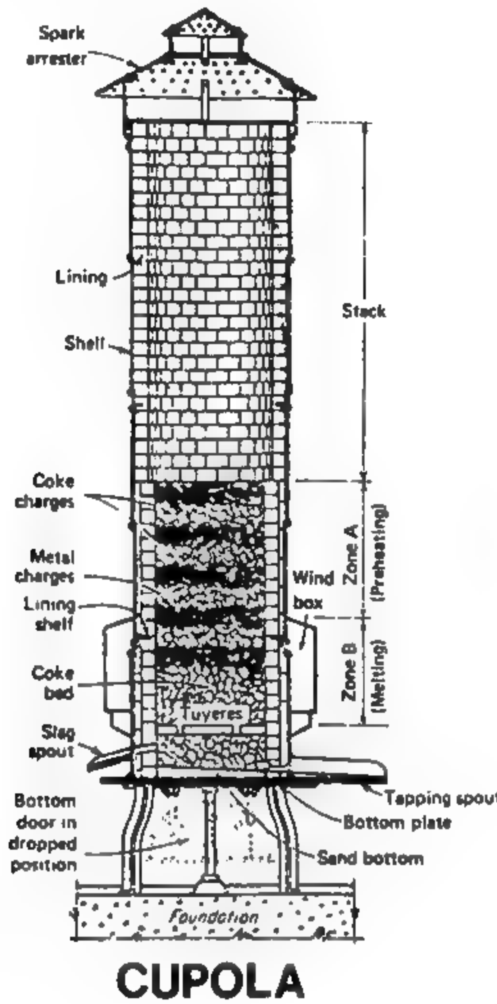


Figure 6-1
Sectional view of a cupola.

porting the bottom doors is removed. The hinged doors swing down, dropping the glowing coke and slag on a bed of sand under the furnace, and water is used to extinguish the fire. After the cupola has cooled, the refractory lining is repaired for the next operation.

Reverberatory

Reverberatory furnaces are used to melt large quantities of nonferrous metals, particularly where alloying is to be done. As shown in Figure 6-2, the furnace is rectangular with a shallow, saucer-shaped hearth and a low, arched roof. Both are lined with refractory material. Oil or gas burners at one end of the furnace direct flames *above* the metal lying on the hearth, heat the roof and side walls of the furnace, and are exhausted at the opposite end. Heat radiated from the refractory roof and side walls

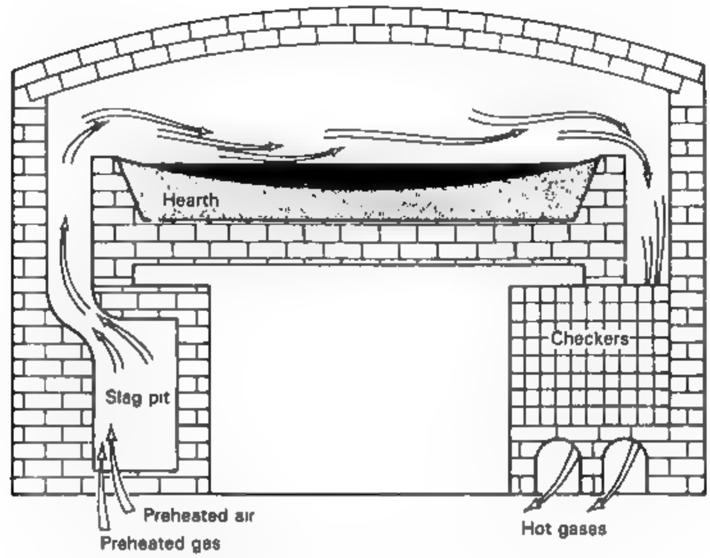


Figure 6-2
Sectional view of a reverberatory furnace.

melts the metal. Once started, the operation can be continuous until refractory repairs are required. As charge metal is added, the level of molten metal rises to the tap hole at one end of the furnace and the metal runs out the spout into the well or a holding furnace from which ladles are filled. Also, metal can be dipped out of the well, as in permanent molding and cold-chamber die casting.

Electric Arc

Electric arc furnaces are fast and clean, and cost-effective where electricity rates are low. They are used to melt steel and cast iron, and are replacing cupola furnaces in many situations in which foundries are being modernized. They use heat from an electric arc to melt high-temperature metals. When the electric arc is between two carbon electrodes and does not contact the charge, the furnace is an *indirect-arc* furnace (Fig. 6-3). When the electric arc is between three carbon electrodes and the charge metal, the furnace is a *direct-arc* furnace (Fig. 6-4). When a direct-arc furnace operates, the three carbon electrodes are raised and the roof is swung to the side. A clamshell charge bucket is positioned over the furnace, and its contents are dropped. The charge bucket is removed, the roof is swung back into place, and the carbon electrodes are moved down toward the charge metal. The low-voltage, high-amperage current establishes an arc and burns holes down through the charge metal with liquid metal collecting in a pool on the saucer-shaped hearth. As the electrodes are raised or lowered slightly to maintain the arc, the pool of molten

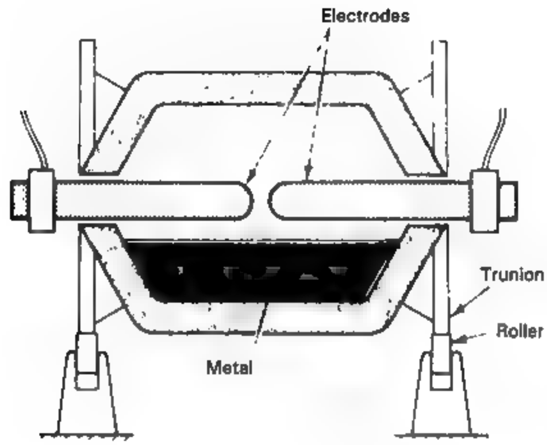


Figure 6-3
Sectional view of an electric indirect-arc furnace. The heat that melts the metal is created from an electric arc established between the two carbon electrodes.

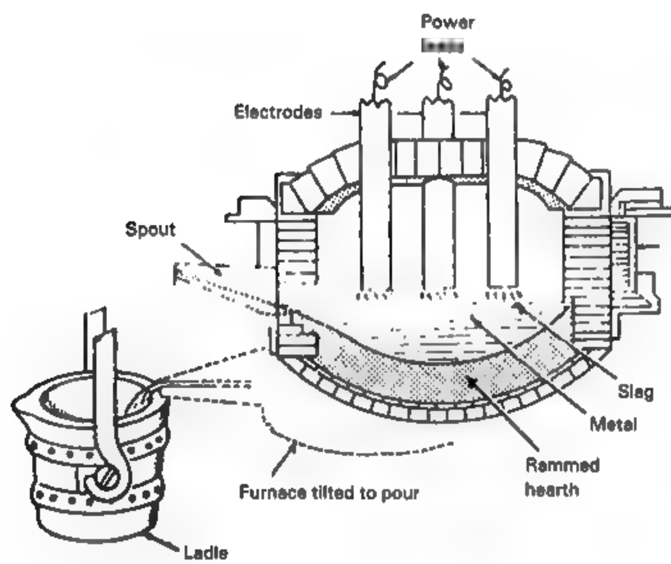


Figure 6-4
Sectional view of an electric direct-arc furnace in which electric arcs are established between the three carbon electrodes and the metal.

metal gets increasingly larger until all of the charge metal is molten. A door is located in the rear of the furnace opposite the spout. This provides for the addition of alloying materials and enables slag to be pulled off prior to emptying the furnace. The furnace is tipped to pour the molten metal into a ladle, which normally transports it to a holding furnace.

Direct-arc furnaces are available in different sizes; a modern foundry might have one or more furnaces with a 14-foot diameter and a melt capacity of about 20 tons per hour.

Induction

Induction furnaces are very efficient. They melt both ferrous and nonferrous alloys rapidly and with little loss from oxidation. There are several types of induction furnaces. Some, called **coreless** induction furnaces, have a coil around the furnace (Fig. 6-5). Others, known as **channel** induction furnaces, have a coil (around a metal core) near a U-shaped channel at the bottom of the furnace (Fig. 6-6). In either case, as electrical current flows through the coil, magnetic fields are established. As the magnetic lines of force pass through the charge metal, a voltage is induced and is followed by a flow of current. The resistance offered by the charge metal to the current flow produces heat, which eventually melts the charge metal. Induction furnaces are made in a wide range of sizes. There are high-frequency, coreless, crucible furnaces of the coil-lift and push-out types that melt from ten to several hundred pounds of metal. Some school foundries that offer college-level instruction in cast metals have such equipment. The larger pieces of induction equipment in industry are drum-type channel (core) furnaces with capacities of up to 87 tons, and coreless furnaces with capacities of up to 80 tons.

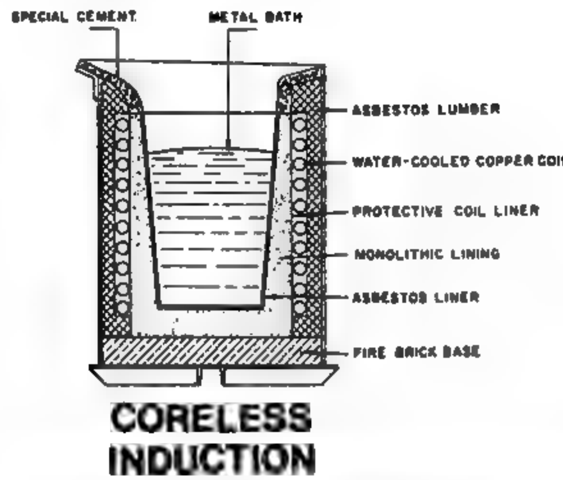
Crucible

The **crucible furnace** is widely used in the nonferrous foundry industry and is the furnace most commonly used in educational settings. The gas-fired crucible furnace shown in Chapter 1 is appropriate for the school foundry. This furnace has an ultraviolet safety system and a special soundproof console that provides pushbutton operation. The speed, durability, and economy of this stationary, lift-out type, natural- or LP-gas–fired furnace, together with its modest floor space requirements and ease of operation, result in its being the most appropriate choice.

When operating a crucible furnace, the metal is placed in a crucible (refractory container), and the crucible is placed in the furnace on a refractory base block that rests on the furnace bottom. The furnace burners direct the flame to swirl around and heat the crucible, the base block, and the refractory lining. Gases escape through a vent in the furnace lid. The size of a crucible furnace is based on the largest crucible the furnace was designed to accommodate. Such a furnace melts a crucible of aluminum in about 12 minutes.

Normally, crucible furnaces are used to melt nonferrous metals, but some specially designed crucible furnaces (for use in educational facilities) are capable of melting gray iron.

The length of the class period, however, can be a limiting factor. If x is used to represent the time it takes to melt aluminum, it will take approximately $1\frac{1}{2}x$ to melt brass and $4x$ to melt gray iron in a crucible furnace. The time factor and the low cost of materials are the main reasons that aluminum is the most commonly used metal in school foundries.



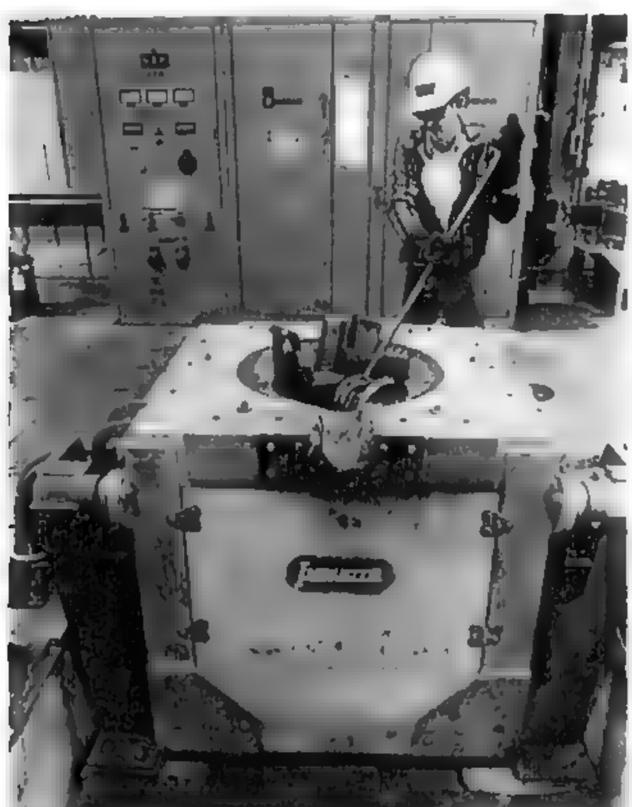


Figure 6-5
Top, sectional view of a coreless induction furnace. Notice the water-cooled coils. *Bottom,* coreless induction furnace in operation.

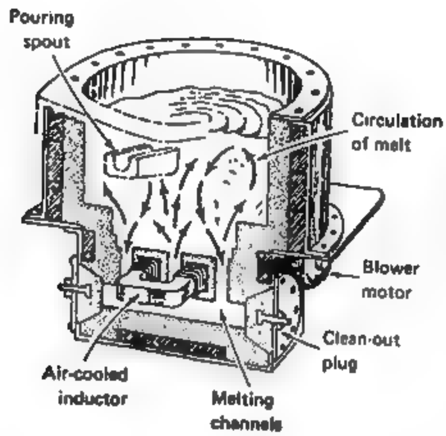


Figure 6-6
Sectional view of a channel induction furnace.

Copper-base alloys (red brass, yellow brass, bronze, and so on) are used to a lesser extent and gray iron is used very little. The longer class time available in vocational or college courses increases the opportunity to use gray iron. However, the higher temperatures required to melt iron greatly increase the operating cost and wear on a crucible furnace. The hazards of handling molten metal of much higher temperature are also a matter of concern. Whether or not you have hands-on experience in pouring gray iron melted in a crucible furnace, you need to remember that crucible furnaces are seldom used for melting gray iron in an industrial setting.

Safety Systems: Most state and/or local codes require blower-operated furnaces to be equipped with a safety system. The two types of safety systems commonly used are the thermocouple system and the ultraviolet system. Both systems provide positive control in the event of gas or electrical interruption or air failure.

A thermocouple system includes a safety switch, thermocouple, solenoid gas valve, and air switch. If it contains an ignition relay and spark transformer, ignition is a pushbutton operation.

An ultraviolet system includes an ultraviolet flame scanner, flame relay, ignition relay, spark transformer, solenoid gas valve, pressure regulator, shut-off valve, and electric ignition system with a start/stop switch. This system shuts down the gas supply in less than a second if the ultraviolet scanner does not detect a flame. The speed with which the main gas supply valve is closed following loss of flame makes this the preferred system.

You should identify the type of safety system that is used on the furnace you will be using and become familiar with how it works.

Care and Maintenance: A certain amount of preventive maintenance will increase furnace life substantially. Avoid getting molten metal on the furnace refractory. Any such deposits should be removed regularly with

a wire brush or cold chisel, if necessary. Some furnace manufacturers recommend a periodic coating of the furnace lining with a refractory wash or sealer.

Observing the following rules will be most helpful in providing proper care for the furnace that you use:

DO NOT

- Use a furnace without a base block of the approximate diameter of the base of the crucible and of the proper height.
- Let metal overhang or splash out of the crucible when charging.
- Charge a crucible so full that molten metal may spill out as the crucible is removed.
- Skim off dross with the crucible in the furnace.
- Overload the lid with metal to be preheated for charging.

DO

- Place a piece of corrugated cardboard between the base block and crucible in a cold furnace—this will develop an ash that should prevent the crucible from sticking to the base block. If the furnace is hot, wet the cardboard.
- Reduce furnace operation, set the crucible off center, or open the lid when all the metal in a full crucible is molten—any of these actions prevents metal from being lifted from the surface and deposited on the wall by the whirling action of the flame. Such actions also prevent overheating and excessive oxidation of the metal.

Proper Venting: Potentially toxic agents such as carbon monoxide are produced during the operation of a furnace. Other harmful agents might be generated in fluxing, degassing, and melting certain metals or alloys. Be sure the exhaust hood over the furnace is operating before the furnace is started.

NOTE: Venting the pouring area is especially important if oil-tempered sand is used for molding.

Furnace Atmosphere: An operating furnace may have a neutral (equal amounts of gas and air), oxidizing (more air than gas), or reducing (more gas than air) atmosphere. The metal being melted can be damaged if the furnace atmosphere for a crucible furnace is not reasonably correct. The ideal atmosphere for a crucible furnace is *slightly oxidizing* (0.5 percent), which results in faster melting, better fuel economy, and less absorption of undesirable gases. Any of the following techniques may be used to achieve the correct furnace atmosphere:

Flame Test

After the furnace has warmed up for a few minutes, adjust controls to obtain a short sharp flame (rather than a high lazy flame) out of the exhaust of the furnace lid. When copper-base alloys are being melted, the flame should be tinged with green. A smoky yellow flame indicates a reducing atmosphere.

Zinc Test

Pass a small strip of cold zinc through the flame at the burner. If the strip turns black, the atmosphere is excessively reducing; reduce gas or increase air. If the strip turns yellow, the atmosphere is slightly reducing; increase air slightly. If the strip does not change, the atmosphere is correct.

Skim Test (used when melting copper-based alloys)

Wearing oxyacetylene goggles, skim an oxide-free area from the surface of the molten metal with a rod. If the skimmed area remains bright and shiny, atmosphere is reducing; adjust air or fuel so that skimmed area films over and becomes dull within a few seconds after skimming.

CRUCIBLES

Crucibles are made of carbon-bonded silicon carbide or clay-bonded graphite. Silicon carbide crucibles

1. Have higher thermal conductivity (transfer heat more rapidly)
2. Have longer life (if not mistreated)
3. Do not require annealing (heating to a dull red and cooling in the furnace *before* first use)
4. Are commonly used in industry

Clay-graphite crucibles are less expensive and more common in school foundries, where inexperienced students sometimes shorten crucible life through unintentional mishandling.

Shape

Crucibles come in a number of shapes, such as bilge, straight-wall, and bowl. The bilge is the standard shape for the stationary, lift-out, fuel-fired furnaces commonly used in school foundries. The bottom-pour crucible in Figure 6-7 has a bilge shape. Bottom-pour crucibles eliminate skimming

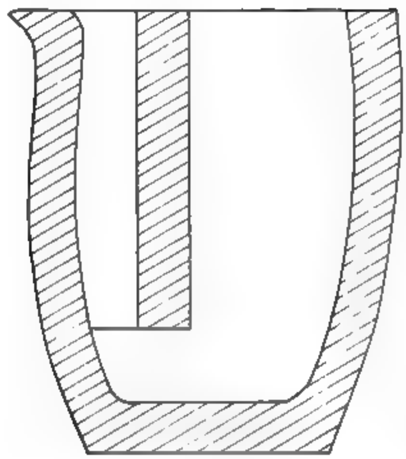


Figure 6-7
Sectional view of a bottom-pour type crucible, which ensures that clean metal is poured.

and ensure that oxidation-free metal is poured, but careful cleaning of the empty crucible is required to prevent oxide build-up when aluminum is melted.

Size

The size of a crucible is indicated by a number such as 10, 16, 20, 30, and so on. If you cannot find the number on the crucible you are using, you can determine its number by checking measurements on the chart in Figure 6-8.

The number of a crucible indicates its working capacity in pounds of *molten aluminum.* It will hold about three times this weight of heavier metals such as copper-base alloys or iron, but more specific information is available from charts. Such information should be used only as a guide. It is *most important* that the level of molten metal be a safe distance below the top of the crucible (minimum of 1 inch) so that it can be handled and moved without spilling. The chart in Figure 6-8 shows the working capacity of various size crucibles for aluminum and a heavier metal such as red brass.

Be sure to use crucibles that are within the range of sizes your furnace was designed to handle. Oversized or undersized crucibles will result in inefficient melting.

Care

Although a crucible can be used for many heats, it is still a fragile object that will break like a dish if it is dropped. There are a number of precautions that should be taken with crucibles.

OUTSIDE MEASUREMENTS					ALUMINUM Working Capacity	RED BRASS Working Capacity
Size	Height	Top Dia.	Bilge	Bottom		
10	8 1/8″	6″	6 9/16″	4 5/8″	10	36
16	9 1/4″	7″	7 7/16″	5 1/4″	16	51
20	10 1/8″	7 13/16″	8 1/2″	6 1/8″	20	80
30	11 1/2″	8 11/16″	9 1/2″	6 13/16″	30	111
50	13 3/4″	10 1/4″	11 13/16″	8 1/4″	50	190

Figure 6-8
Chart of dimensions and working capacities of crucible sizes commonly used in school foundries.

In Use

1. Check for soundness by tapping lightly with a hammer handle. A sound crucible should produce a clear ring—a dull sound indicates a cracked crucible.
2. Crucibles should *not* be used for more than one kind of metal or alloy. The residue from the preceding melt may contaminate the present one.
3. Charge crucibles with loosely packed, broken gates, runners, risers, and so on, *before* placing the crucible in furnace. The metal should be able to rattle.
4. Be sure none of the metal sticks out above or overhangs the edge of the crucible. Overhanging metal can melt and run down outside of the crucible. Metal that sticks out above the crucible is subject to excessive oxidation.
5. Be sure the base block is centered in the furnace and the crucible is centered on the base block. Check the condition of the base block regularly.
6. Place a piece of corrugated cardboard on the base block before setting the crucible into a cold furnace. The cardboard produces an ash that prevents the crucible from sticking to the base block. If the furnace is hot, wet the cardboard.
7. Preheat additional charge metal by placing it on the furnace lid (make sure the metal does *not* overhang the exhaust port) *to drive off all moisture.* This step uses energy that would otherwise be wasted, shortens melt time, and eliminates one source of gas porosity by driving off the gases and moisture on the surface of cold metal.

NOTE: Moist metal (even metal moist from condensation from high humidity) added to molten metal could cause a serious explosion to occur.

8. When the original charge has formed a molten pool in the bottom of the crucible, add preheated metal as fast as possible to bring the level of metal up to a safe distance below the top edge. Add metal carefully with tongs to avoid splashing. Make sure that the pieces of metal are long enough to stand vertically or shorter than the inside diameter of the crucible to avoid a situation in which pieces in a horizontal position could expand before melting, thus causing undue pressure on the sides of the crucible.
9. Use the *minimum* amount of flux necessary. Although flux tends to shorten crucible life, it is commonly used in industry to ensure that poured metal has the best physical and mechanical properties. **Cover fluxes** are designed to: 1) prevent pickup of oxygen, hydrogen, and nitrogen; 2) reduce dross formation by oxidation; and 3) reduce metal loss. Degassing materials are used to purge the melt of undesirable hydrogen gas.
10. Handle hot crucibles with tongs that are designed to hold the crucibles securely without pinching or chipping the top edge or placing undue pressure on the side walls of the crucible. Commercially manufactured tongs with an adjustable stop to control squeeze pressure are recommended.

After Pouring Molds

1. Empty excess metal into ingot molds. Metal allowed to solidify in the bottom of the crucible will, upon reheating, expand faster than the crucible and cause premature failure of the crucible.
2. Scrape the inside of the crucible carefully while it is still hot with a blunt-edged, spoon-shaped scraper, and empty scrapings into a skimming bucket.
3. Return the crucible to the furnace or store in an out-of-the-way place so it can cool at its own rate of speed, and personnel will not come into accidental contact with it.

PYROMETRIC EQUIPMENT

Devices that determine temperatures above those that can be measured with a mercury thermometer are called **pyrometers.** Industry finds much use for surface, immersion, and optical pyrometers.

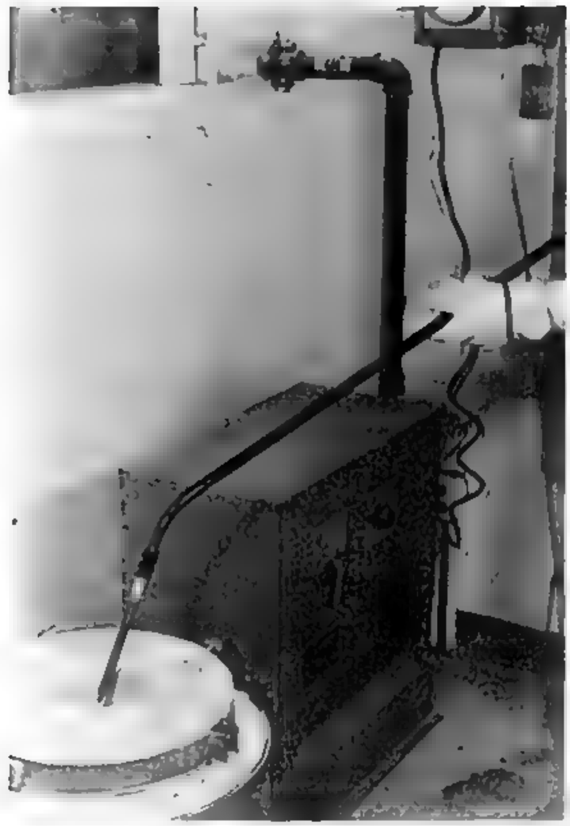


Figure 6-9
Immersion-type pyrometer.

A pyrometer with an immersion thermocouple is most commonly used in school foundries (Fig. 6-9). This is a simple and accurate piece of equipment. The thermocouple portion of the pyrometer consists of two dissimilar metals (in wire form) insulated from each other, joined together at the hot end and leading back to a cold junction to form a circuit. When the hot junction is immersed in molten metal, a current flows owing to a voltage difference across the junctions. The voltage produced is almost directly proportional to the temperature difference between the hot and cold junctions, and a sensitive millivolt meter is used to indicate the temperature directly. An immersion-type pyrometer with a temperature range of 0–2500F (−18–1340C) can be used for both aluminum and copper-base alloys if the thermocouple is cleaned between uses with different kinds of metal.

Experienced melters can often judge the temperature of metal quite closely but this takes a practiced eye. It is much better to use a pyrometer to determine important temperatures, such as the furnace shut-off temperature, the peak temperature of the melt, and the pouring temperature.

In using an immersion pyrometer, preheat the *coated* thermocouple to slightly above the anticipated temperature of the molten metal and then quench it by inserting it directly into the molten metal. This technique provides a temperature reading in seconds and greatly reduces thermal erosion of the pyrometer.

If pyrometric equipment is not available, a melting schedule can be worked out that will ensure some success. For example, when melting aluminum, a close monitoring of the melt enables one to know when all the charge is completely molten. Run the furnace another 2 minutes and shut down. Remove the crucible, wait 2 minutes, degas, skim, and pour. Pour thinner castings first and heavier castings later. Pour fast. The resultant castings will validate the schedule or provide a clue as to how the schedule should be modified to produce better results.

TOOLS USED IN MELTING

A number of tools are used in melting metal.

Tongs

Blacksmith tongs are used to add metal to the crucible when the original charge is molten. The tongs should be able to handle several thicknesses of material safely.

Rod

An ordinary steel rod with an eye at the top to serve as a handle (and for hanging) is useful on occasion. It should *not* be used for *stirring* molten metal or for *forcing* unmelted metal into a crucible. The "working end" should be coated and preheated before being used.

Skimmer

Unless a bottom-pour crucible is used, a skimmer is required for removing **dross** before pouring. Skimmers can be purchased or made. It is important that the skimmer is not too large for the crucible. A skimmer with a 3-inch (76-millimeter) diameter bowl works well with No. 10 and No. 16 crucibles. Skimmer bowls are perforated with a number of small holes (Fig. 6-10). Mild steel skimmers will provide satisfactory service for aluminum. Stainless steel skimmers are better for metals that melt at higher temperatures. A skimmer should be coated and preheated *before* being used.

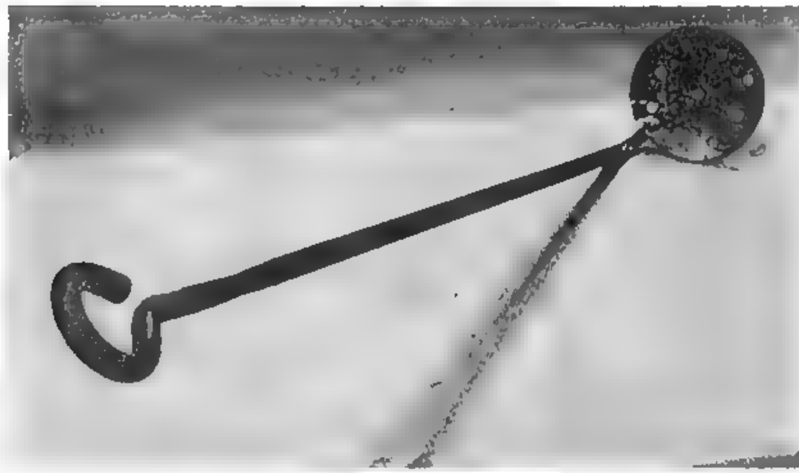


Figure 6-10
Shop-made skimmer of mild steel; stainless steel would be better.

Flux Scoop

A scoop shaped like a skimmer (but without holes) is useful for adding a measured amount of flux to the crucible. The furnace lid can be swung to one side and the flux added with the furnace running or shut down (Fig. 6-11).

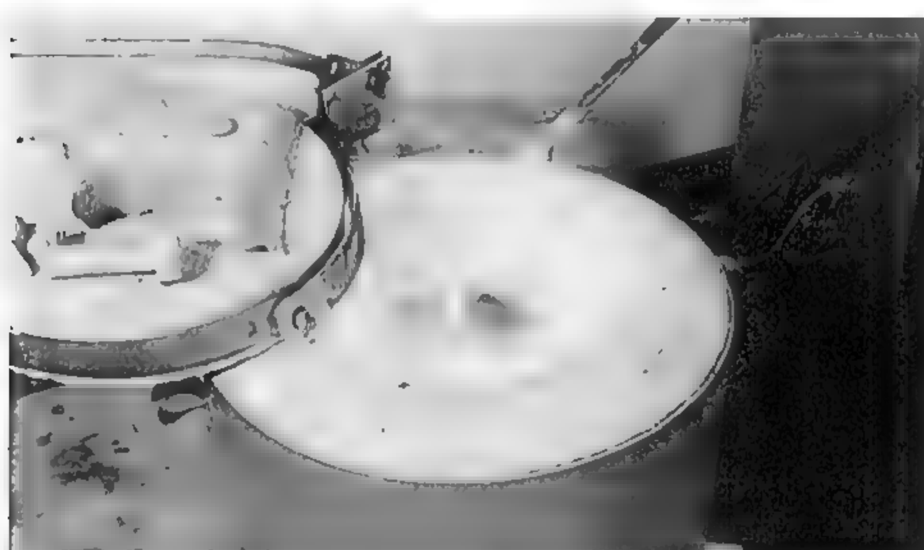


Figure 6-11
A flux scoop enables flux to be added without shutting down the furnace.

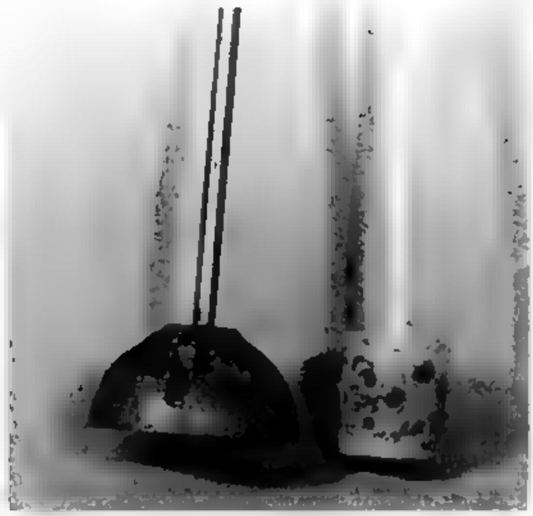


Figure 6-12
Left, small, industrial, bell-shaped plunger. *Right,* shop-made basket plunger.

Plunger

A plunger is necessary for pushing degassing tablets to the bottom of aluminum melts. Plungers are made in a variety of designs, the most common being bell-shaped or basket-type (Fig. 6-12).

Industrial plungers are generally too large to be of use in the school foundry. Basket-type plungers are available from some school shop suppliers or can be made. A 3-inch (75-millimeter) length of pipe with a number of ⅜-inch (10-millimeter) holes drilled through the sides, a ¼-inch (6-millimeter) disc welded to one end of the pipe, and a handle welded to the center of the disc make a plunger of an appropriate size for No. 10, No. 16, No. 20, and No. 30 crucibles.

It is most important that plungers be *cleaned, coated,* and *preheated before* being used. After being used, plungers normally have accretions of hygroscopic (moisture-retaining) material attached to them that should be removed prior to reusing the plunger. If these are not removed, the effectiveness of degassing may be reduced, and some hazard may result from moisture (in the accretions) reacting violently with the aluminum.

COATING TOOLS USED IN MELTING

Steel tools, such as pyrometers, skimmers, plungers, and stirring rods, that are dipped into molten nonferrous metals should be coated with some refractory material to prevent iron pick-up and to prolong the life of the tools. **Iron pick-up** is a contaminant that results from molten nonferrous metal coming into contact with iron or steel tools. Excessive iron pick-up will cause aluminum to develop **spangles** as it solidifies, causing it to look somewhat like galvanized iron. Increased shrinkage problems are associated with such aluminum. A slurry of equal parts of whiting (a fine, white powder of calcium carbonate) and silicate of soda can be used to

Figure 6-13
Steel tools that contact molten metal should be coated with a refractory wash. This includes ingot molds (not shown).

coat the tools and prevent such contact. Proprietary materials such as FOSECO's Firit have been developed specifically for this purpose.

Firit tool coating is a powder that is mixed by adding the powder to water until it reaches a slurry consistency. Then the slurry should be allowed to stand for 12 hours to fully develop the bond. Tools should be warmed to about 180F (80C), after which they can be coated by dipping, brushing, or spraying (Fig. 6-13). Several thin coats are better than one thick coat. Tools coated in this manner *must be heated* to drive off *all moisture* before being used.

TOOLS USED IN POURING

Metal melted in crucibles of the size used in school foundries is usually poured directly from the crucible into the mold. Special tools are used to handle the hot crucible. **Crucible tongs** are used to remove the crucible from the furnace and place it in a **crucible shank** for pouring.

Crucible Tongs

Tongs are made to fit only *one* size crucible. The tongs must be designed to support but not place undue pressure on the crucible walls and to provide top clearance to prevent pinching and chipping of the top edge, which can be a major cause of crucible failure.

Plain Crucible Tongs (One-Person): Smaller crucibles are usually handled with plain crucible tongs designed to be used by one person (Fig. 6-14). A desirable feature is an adjustable stop, which ensures that excessive pressure is not applied to the walls of the crucible. New crucibles vary slightly in size and all crucibles erode with use. The stop should be

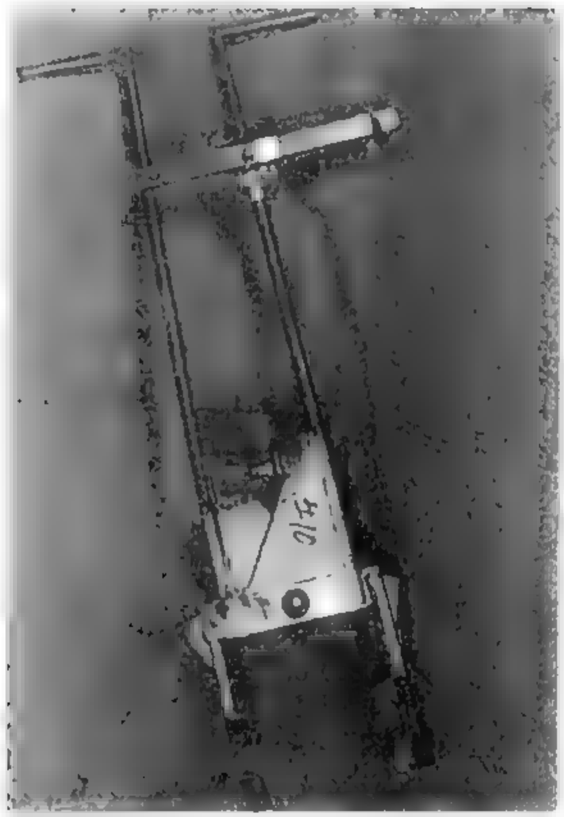


Figure 6-14
Plain (one-person) crucible tongs.

adjusted as necessary for the tongs to fit properly on a *hot* crucible. Another desirable feature, especially for plain tongs, is a locking bar.

Bent-Handle Crucible Tongs (Two-Person): Larger crucibles are usually moved with bent-handle tongs, designed to be used by two persons. However, such tongs are made for crucibles as small as No. 10. If sufficient space exists around the furnace, the use of bent-handle tongs is advantageous regardless of crucible size. Two people share the weight of the crucible, and those persons are farther from the heat of the furnace and crucible. Also, the handles are designed so that lifting action on the handles provides a very positive grip on the crucible. An adjustable stop ensures that undue pressure is not exerted on the side walls of the crucible. Some bent-handle crucible tongs have a **latch bar** with a notch to hold the tong jaws open for installing over the crucible and possibly another notch to lock the jaws in position. Such a locking arrangement is not essential with bent-handle tongs, since there is no way the crucible can come out of the tongs as long as there is a lifting action on both handles.

Crucible Shanks

Crucible shanks are available with a variety of design features, but are classified as either fixed band (for one specific size crucible) or adjustable

(with support pads that can be moved to fit two or more crucible sizes). Since most crucible furnaces used in school foundries are designed to accommodate a range of crucible sizes (such as No. 10–No. 16), *adjustable* crucible shanks of the same size range usually are purchased. Additionally, crucible shanks are designed to be used by one person (hand shanks) or two persons (single-end shanks).

Adjustable, Hand Crucible Shank (One-Person): Techniques appropriate to industry are not always equally useful in an educational setting where learners are involved. This is the case with the one-person, adjustable or nonadjustable, hand crucible shank (Fig. 6-15). *It should not be used by inexperienced students in a school foundry.*

Adjustable, Single-End Crucible Shank (Two-Person): Whenever possible, pourers should use an *adjustable, single-end crucible shank (two-person)*. The weight of the crucible and its molten metal is easier for two persons to lift and control. Also, those pouring are farther from the crucible than when a pourer is using a one-person hand shank. The shank should have the following safety features:

- Adjustable pad supports below the bilge of the crucible
- Tubular handles (to reduce weight)
- Handles offset at the band (to provide better crucible balance when pouring)

Figure 6-15
Hand crucible shank used by one person to pour molds.

- A locking device (to hold the crucible securely, even when the shank is inverted)
- Three safety legs (refer to Fig. 1-5)

The conventional single-end crucible shank (without safety legs) is normally used by placing the band of the shank on two firebricks or a mound of dry sand. (A hot crucible should not be placed on concrete because it will spall the concrete or at least leave a scorch mark.) The crucible is then placed in the center of the band, after which the shank is raised to "capture" the crucible. The shank's spring-loaded safety finger is positioned on the top edge of the crucible and pouring proceeds.

A serious problem with the procedure described above is that when the crucible is set on the firebrick or sand in the center of the band, it is free-standing (unsupported) *until* the shank is raised to capture the crucible. Basically, the shank is more or less balanced on the firebrick or sand. Anyone tripping on either shank handle could tip over the crucible and cause a spill of molten metal of serious proportions.

The safety legs suggested above

1. Provide extremely stable support for the shank (it does not have to be balanced on its band)
2. Greatly reduce the possibility of tipping over a crucible of molten metal should someone trip over the shank handles
3. Hold the band off the floor so the crucible can be released from the tongs directly into the shank—the crucible is never left in a hazardous free-standing position
4. Do not interfere in any way with pouring
5. Eliminate the need for firebrick or a mound of dry sand in the pouring area, which could provide a stumbling hazard.

It is recommended that school foundries with conventional shanks modify them with the addition of safety legs.

Ingot Molds

Metal remaining in the crucible after all the molds are poured is emptied into **ingot molds** (Fig. 6-16). These are available from school shop suppliers, or they can be made. It is important that such molds produce ingots of a size that can fit in a crucible with room to expand without damaging the crucible. The ingots should either be long enough to be inserted into the crucible vertically (without standing above the lip of the crucible) or ½ inch (13 millimeters) shorter than the smallest inside diameter of

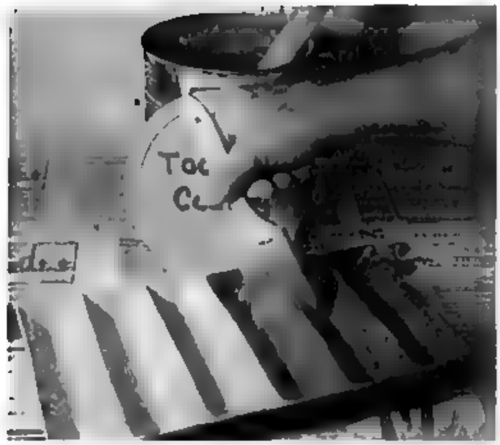


Figure 6-16
Ingot mold partially coated with a suitable "wash."

the crucible. The ingot molds should be *coated* and *dried thoroughly* before being used.

POURING FLOOR

Special provision should be made to accommodate the pouring of molds in the school foundry. This has been handled in many different ways. It is important to keep molten metal from coming into contact with concrete. If moisture exists in the concrete, the metal and/or concrete might pop from the original surface with explosive force. Even if the concrete is quite dry, molten metal can damage concrete through spalling or at least leave an undesirable scorch mark on the concrete.

The usual practice is to set aside a pouring area and protect the concrete in this area with dry sand. Since the protective sand is often different from the molding sand, some means should be devised to keep the pouring floor sand from being mixed in with the molding sand. Some school foundries enclose the pouring area with concrete blocks or angle iron, but this creates a stumbling hazard.

Another system (Fig. 6-17) uses a shallow pit with a metal grate (to preserve floor height) and with sufficient dry sand added to the pit to protect the concrete.

TOOL PANEL FOR MELTING AND POURING TOOLS

It is necessary to make some arrangement for safely storing the various tools and materials used in melting and pouring. The tool panel shown in Figure 6-18 is an example of what can be done to increase efficiency in the melting and pouring area.

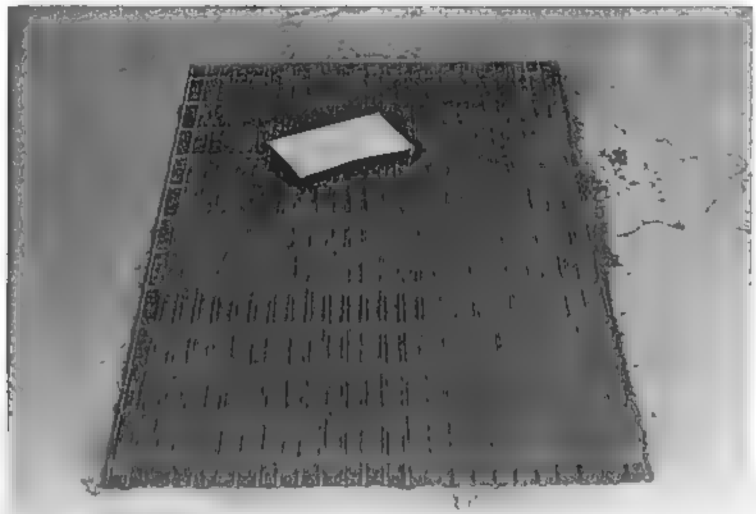


Figure 6-17
Pouring floor—a shallow pit with a floor-level metal grate and dry sand.

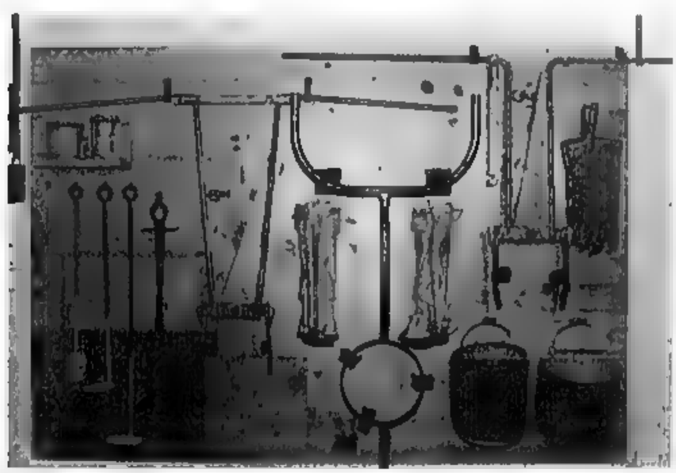


Figure 6-18
A tool panel to accommodate melting and pouring tools and equipment.

METAL

Castings are made of a great variety of metals and alloys. In industry, alloys of cast iron represent the greatest tonnage of castings produced. In school foundries, metals and alloys with lower melting temperatures are more appropriate.

Considerations such as the length of instructional periods, melting

equipment, and material cost make aluminum the first choice for most educational settings. Red and yellow brass, if available at low cost, are popular.

Aluminum and copper-base alloys *known to be suitable for metal-casting should be used.* New material is much less problematic than scrap. A nearby nonferrous foundry usually will sell metal at cost to schools. This could result in substantial savings, since metal purchased in large quantities by a foundry would be substantially lower in cost than material purchased from school shop suppliers.

Scrap Metals

Some school foundries use a great deal of scrap metal in their programs. If scrap metals are used (and a new interest in conservation practices provides adequate justification for this), the following points should be observed:

1. Sort the metal carefully.
2. Clean the scrap *before* melting. Remove dirt, carbon residue, grease, oil, and paint. Use an appropriate solvent if necessary. Hydrocarbon materials do not just burn off or combine with slag on top of the melt. When heated, they break down into hydrogen and oxygen. These are absorbed by the molten metal. Such metal, unless properly degassed, produces porous castings.
3. Be sure that material in the initial charge (and in later additions) is *dry.*
4. Do not pour castings from a melt of scrap—skim off dross, and pour the molten metal into ingot molds. The resulting ingots can be used in later melts, mixed with *new* metal (if available) in a ratio of 1:1 or 1:2, scrap metal to new metal.

Aluminum

There are a number of good general-purpose aluminum alloys for sand casting. One of the most commonly used is Alloy 319. It is a composite alloy consisting of aluminum and two principal alloying elements—about 6 percent silicon (Si) and 3.75 percent copper (Cu). This amount of silicon provides good fluidity, enabling the molten metal to fill molds even when thin sections are being cast. The percentage of copper enables the casting to solidify without small cracks developing as it cools, and improves machinability. Alloy 319 also has low shrinkage. If 319 ingot aluminum is available, you can use it with confidence and avoid many of the casting problems associated with a number of other aluminum alloys.

Where scrap aluminum is used, much care must be taken in sorting the scrap and possibly in alloying it, to achieve good castings.

It is important to sort **wrought** aluminum from scrap *cast* aluminum. Any wire, sheet, bar, tubing, extrusion, flat stock, bolts, and so on, are wrought (noncast) aluminum. This material has very little silicon (0.3 percent) or copper (0.7 percent). It *cannot* be used for making successful metal castings *unless* it is alloyed.

After wrought aluminum scrap has been separated from cast aluminum scrap, separate the cast material into that which was cast in sand molds and that which was *die cast* or made in *permanent molds.* Castings made in sand molds can be identified by the sandy appearance on surfaces that have not been machined, by parting lines, and by evidence that gates have been removed. Pump and machining housings, heavy cooking pots, and lawn furniture are some examples of sand cast aluminum products. Such scrap, if clean, can be used successfully without alloying.

The other cast materials, parts made in permanent molds or by die casting, generally have too much silicon to be successfully sand cast without alloying. Using this material results in severe shrinkage (and machining) problems. Lawnmower engines and decks, transmission housings, and aluminum pistons (rings removed), blocks, and heads from automobiles and outboard engines are examples of products that are commonly made by die casting or permanent molding. Such material has an average Si content of 9.5 percent and Cu content of 3.5 percent.

NOTE: It is *very important* that *zinc* die cast parts (sometimes called "pot metal") such as carburetors, car door handles, knobs, hood ornaments, grills, and so on, do not contaminate your melting stock. *Discard all such material.*

Sorting as described produces four distinct types of scrap material.

- Wrought aluminum (Si 0.3 percent, Cu 0.7 percent), must be alloyed
- Sand cast aluminum, which can be used as is
- Permanent mold/die cast aluminum (Si 9.5 percent, Cu 3.5 percent), must be alloyed
- Die cast zinc (pot metal), which should be discarded

The wrought aluminum and permanent mold/die cast aluminum (PM/DC) can be alloyed into useful sand casting material. A charge made up of 40 percent wrought aluminum scrap (sheets, rods, and so on) and 60 percent die cast or permanent molded scrap (pistons, lawnmower engines, and so on) produces an alloy with an Si content of about 5.8 percent and a Cu content of about 2.38 percent.

Example:

	Si	Cu	Si	Cu
Wrought	0.3%	0.7% × 40% =	.12%	.28%
PM/DC	9.5%	3.5% × 60% =	5.70%	2.10%
			5.82%	2.38%

This compares rather favorably to Alloy 319 (Si 6.0 percent, Cu 3.75 percent). The 1.37 percent deficit in Cu content can be eliminated by adding ¼ ounce of pure copper wire per pound of charge metal. The copper wire should be very fine, clean and free of all insulation. Make a bundle of the wire and push it to the bottom of the melt with a plunger when the temperature of the molten metal is 1200F (650°C).

Such alloying produces a material of approximately the same chemistry and characteristics of Alloy 319. The fluidity of the material can be increased or decreased as needed by using slightly more or less of the PM/DC alloy. Additional copper can be added, if necessary, to solve cracking problems.

Copper-Base Alloys

A common copper-base alloy used for sand casting is red brass C83600 (85-5-5-5). This alloy contains 85 percent copper and 5 percent each of tin, lead, and zinc. Yellow brass is another copper-base alloy commonly used for sand casting.

There are so many varieties of copper-base alloys that the identification of appropriate scrap by eye is not very reliable. But then, it need not be. Brass can usually be identified by its color and weight. Examining a newly filed surface should help to eliminate nonbrass as well as to separate red and yellow brass. Using clean scrap, consisting of brass *castings* (rather than wrought brass scrap), results in fewer casting problems attributed to the metal.

MOLTEN METAL TREATMENT PRODUCTS AND PROCESSES

Metal melted in an industrial setting is commonly treated with materials designed to ensure that it is in suitable condition when poured. Aluminum and copper-base alloys such as red and yellow brass *can* be melted and poured without such materials. However, the use of cover fluxes, degassers, deoxidizers, and so on in the school foundry will reflect industrial procedures as well as produce better castings.

The materials described below can usually be found at a local foundry.

The manufacturer's recommendations for using such materials should be followed exactly.

Proper Use of Molten Metal Treatment Products for Aluminum

Aluminum should be melted under a **cover flux** such as FOSECO's Coveral 11. This pink powder is used at the rate of ¾ pound per 100 pounds of metal. For small crucibles, this converts to one level half teaspoon of flux per pound. The flux is added in *two stages*. Add half of the total amount when the initial charge starts to melt. Add the other half when the total charge is completely molten. The cover thus provided should not be disturbed until degassing is done. When the furnace has been shut off, monitor the melt; when the **temperature peaks,** treat the melt with a **degasser.**

For instance, FOSECO's Degasser 190, in the form of 2-ounce, solid, blue tablets is used at the rate of one tablet per 50 pounds of aluminum. A No. 10 crucible in which 10 pounds of aluminum is melted requires ⅕ tablet. One third tablet is the proper amount for a No. 16 crucible with about 16 pounds of aluminum.

After the temperature of the melt has peaked, move the crucible from the furnace to a crucible shank. Pull the surface dross to one side and drop a degasser pellet of the proper size on the clean surface. The degasser will float, so use a clean, coated, and preheated basket plunger to push it to the bottom. When bubbling ceases and smoke and fumes no longer rise from the melt, stir the metal by pumping the plunger up and down slowly two or three times *without breaking the surface.* The plunger is then removed. Wait a minute or two to allow the gas and dross to float to the surface, then skim and pour the metal.

Proper Use of Molten Metal Treatment Product for Red Brass

It is best to use a cover flux when melting red brass. For example, one pound of FOSECO's **Cuprex 100** flux (black powder) per 100 pounds of metal is added with the charge *or* when the metal starts to melt. For small crucibles, this converts to one level half teaspoon per pound. A No. 10 crucible filled to its working capacity of 36 pounds requires ⅜ cup. A slightly rounded ½ cup of Cuprex 100 is the proper amount for a No. 16 crucible with about 57 pounds of red brass. Cuprex 100 provides an oxidizing cover that retards the absorption of hydrogen gas in the melt. When the temperature of the melt is appropriate for pouring, skim the surface. Adding a small amount of clean, *thoroughly dry* silica sand, or **slag coagulant** (such as FOSECO's Slax 10) simplifies this task. **Phos-**

copper shot at the rate of 2 ounces per 100 pounds of metal should be added just before pouring. For small crucibles, this converts to 1 level teaspoon for a No. 10 crucible and 1½ teaspoons for a No. 16 crucible. The shot will deoxidize and control the hydrogen content of the melt, increase fluidity, reduce porosity, and produce cleaner castings with better surface finish and detail.

Proper Use of Molten Metal Treatment Products for Yellow Brass

The procedure for melting yellow brass is similar to that for melting red brass except that a different flux is used. Add one pound of suitable flux, such as FOSECO's Cuprit 49 flux (white powder), per 100 pounds of metal when making up the charge or when the metal starts to melt. For small crucibles, this converts to one level teaspoon per pound. A No. 10 crucible filled to its working capacity of 36 pounds requires a rounded ⅝ cup. A level cup of Cuprit 49 is the proper amount for a No. 16 crucible with about 53 pounds of yellow brass. After skimming, add phos-copper shot (at the rate of 2 ounces per 100 pounds) just before pouring. For small crucibles, the amounts are the same as specified under red brass, above.

MELTING

In industry, large foundries have melt departments (Fig. 6-19) whose chief responsibility is to have properly treated metal of the right temperature available at the pouring site when the mold is ready to be poured. This takes a great deal of cooperation on the part of many people.

In the school foundry, those who make molds are often responsible for melting and pouring as well. Melting is usually started before molding is completed. Careful timing of molding and melting is required to have the metal ready when the mold is ready for pouring. This is simplified if a student who has no other responsibilities can supervise the melting.

Many mistakes can be made in melting if the process is not properly monitored. For example, the most common mistake when melting aluminum is overheating it.

The melting procedure described below assumes a cold furnace, which is common in school foundries where short instructional periods scattered throughout the school day often result in intermittent melting. If the school situation lends itself to more frequent melting, the process will be more energy- and time-efficient. Procedures for both aluminum- and copper-base alloys are provided. A procedure for iron is not given since *the melting of iron in a crucible furnace is not an industrial process*

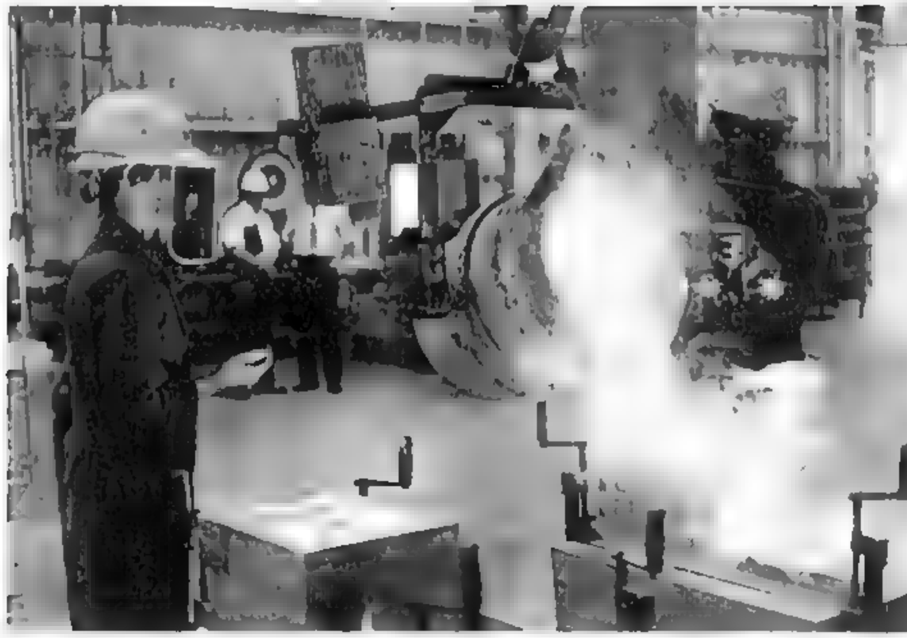


Figure 6-19
The melt department must have metal ready to pour when it is needed.

and few school foundries have melting equipment other than a crucible furnace.

Aluminum

1. Weigh out the appropriate amount of suitable size metal (for example, 10 pounds of aluminum for a No. 10 crucible).
2. Fill the clean crucible with small pieces in the bottom and loosely packed material above. Be careful to allow room for the metal to expand without damaging the crucible. The metal should be able to rattle.
3. Center the base block in the furnace and place a piece of cardboard on it.
4. Center the crucible on base block.
5. Place the remaining charge metal on the furnace lid but not overhanging the center port (see Fig. 1-2).
6. Be sure that lid is swung to one side and the exhaust fan is on.
7. Light and adjust furnace for uniform combustion.

8. After several minutes of warm-up, close the lid and adjust the furnace for proper atmosphere (page 178).
9. At the first sign of melting, add ½ the total amount of flux.
10. When initial charge metal has melted, add preheated metal to the crucible until a safe liquid level (minimum of 1 inch below the top of the crucible) has been added (Fig. 6-20).
11. When all charge metal is molten, add the other half of the flux and place the *coated* thermocouple of a pyrometer over the center port of the furnace lid to preheat.
12. Monitor the furnace for a shut-off temperature of 1275–1350F (690–732C), depending on type of casting. Refer to Figure 6-21, Melting and Suggested Pouring Temperature Chart.
13. When shut-off temperature has been reached, shut off the furnace, swing the lid to the side, place the thermocouple of the pyrometer in the melt, and place the skimmer and plunger in the furnace and the ingot molds on the furnace lid for preheating (Fig. 6-22).
14. When the temperature peaks, remove the crucible and place it in the crucible shank (Fig. 6-23).
15. Pull surface dross to one side, drop degassing pellet on the surface of the metal, capture it with a clean, preheated, coated plunger, and push it down to the bottom of the melt (Fig. 6-24).

Figure 6-20
When the original charge is molten, additional preheated metal can be added.

	Melting Point	Light Castings under ½" (13 mm.) section	Medium Castings ½"–1½" (13–38 mm.) section	Heavy Castings over 1½" (38 mm.) section
Aluminum	1218°F (660°C)	1350°F (733°C)	1310°F (710°C)	1275°F (690°C)
Red Brass	1952°F (1067°C)	2200°F (1250°C)	2190°F (1200°C)	2100°F (1150°C)
Yellow Brass	1877°F (1025°C)	2125°F (1164°C)	2050°F (1120°C)	1930°F (1055°C)

Figure 6-21
Melting and Suggested Pouring Temperatures Chart.

Figure 6-22
After the furnace has been shut off, monitor the temperature rise with the pyrometer and preheat the plunger, skimmer, and ingot molds.

16. When bubbling ceases and smoke and fumes no longer rise from the melt, stir the metal by pumping the plunger up and down slowly *without breaking the surface.* Remove plunger.
17. Wait a minute or two to allow the gas and dross to float to the surface.
18. Skim—use a preheated, coated skimmer.

Figure 6-23
Crucible is removed from the furnace and placed in a crucible shank before degassing and skimming.

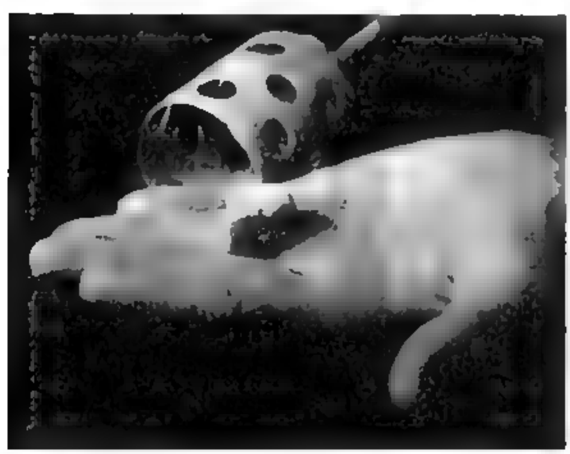


Figure 6-24
When temperature peaks, degassing pellet is plunged to bottom of melt with preheated plunger. This should be done where fumes that are produced will be exhausted.

19. Check temperature of melt with a preheated, coated pyrometer.
20. See page 203 for pouring instructions.

Brass (Red or Yellow)

1. Weigh out the appropriate amount of suitable size metal (for example, 36 pounds of brass for a No. 10 crucible).
2. Fill clean crucible with small pieces in the bottom and loosely packed

material above. Be careful to allow room for the metal to expand without damaging the crucible. The metal should be able to rattle.

3. Center the base block in the furnace; put a piece of cardboard on it.
4. Center the crucible on the base block.
5. Place remaining charge metal on the furnace lid but not overhanging the center port (Fig. 1-2).
6. Be sure that lid is swung to one side and the exhaust fan is on.
7. Light and adjust the furnace for uniform combustion.
8. After several minutes of warm-up, close the lid and adjust the furnace for proper atmosphere (see page 178).
9. At the first sign of melting, add the flux, ⅜ cup of Cuprex 100 flux (black powder) per 36 pounds of red brass (Fig. 6-25) *or* ⅝ cup of Cuprit 49 (white powder) per 36 pounds of yellow brass. Have the proper amount measured onto the flux scoop.
10. When the original charge metal has melted, add preheated metal to the crucible until a safe liquid level (minimum of 1 inch below the top of the crucible) has been reached (Fig. 6-20).
11. Place the *coated* thermocouple of the pyrometer over the center port of the furnace lid to preheat.

Figure 6-25
For red brass, ⅜ cup of flux per 36 pounds of metal is measured onto the flux scoop to be added to the crucible at the first sign of melting.

Figure 6-26
Preheat the skimmer in the furnace and ingot molds on the furnace lid.

12. Monitor the furnace for a shut-off temperature of about 100F (38C) *above* the desired pouring temperature (see Fig. 6-21, Melting and Suggested Pouring Temperatures Chart).
13. When shut-off temperature has been reached, shut off the furnace and swing the lid to the side. Remove the crucible and place it in the crucible shank (Fig. 6-23).
14. Place the skimmer in the furnace for preheating. Place ingot molds on furnace lid for preheating (Fig. 6-26).
15. Skim the molten metal. If the slag is too fluid, it may be thickened to make skimming easier by adding a small quantity of clean, *thoroughly dry* silica sand or a proprietary slag coagulant such as Slax 10. Use a preheated, coated skimmer.
16. **Deoxidize** and/or **fluidize** by adding the appropriate amount of phoscopper shot.
17. Check the temperature of the melt with a preheated, coated pyrometer.

POURING

1. Pour molds—*thinnest castings first.* Keep the lip of the crucible as close to the pouring basin as possible and pour *fast* to keep the sprue full (Fig. 6-27).

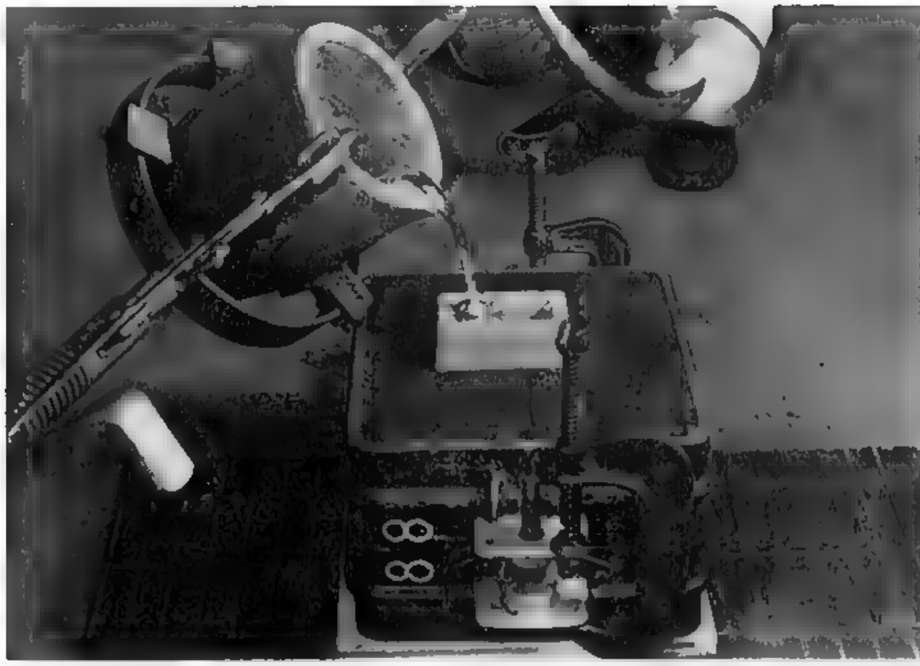


Figure 6-27
Pour fast (try to keep the sprue full) and keep the lip of the crucible as close to the pouring basin as possible.

NOTE: Even though extensive precautions are taken, **runouts** sometimes occur during pouring. Before pouring begins, at least two persons wearing protective clothing should be standing nearby, each with a shovelful of tempered molding sand. At the first sign of a runout, a shovelful of sand is pressed and held against the flask at that point. This controls the runout at the source and is better than the usual practice of throwing sand on a bottom board that may already be badly scorched or burning from an unanticipated runout.

2. Empty extra metal into preheated, coated ingot molds (Fig. 6-28).
3. Use a blunt-edged, spoon-shaped scraper to lightly scrape the inside of the crucible (Fig. 6-29).
4. Empty scrapings into skimming bucket.
5. Set crucible back in the furnace or in a safe, designated place for cooling.

Figure 6-28
Extra metal should *never* be allowed to solidify in the crucible. Pour it into preheated, coated ingot molds.

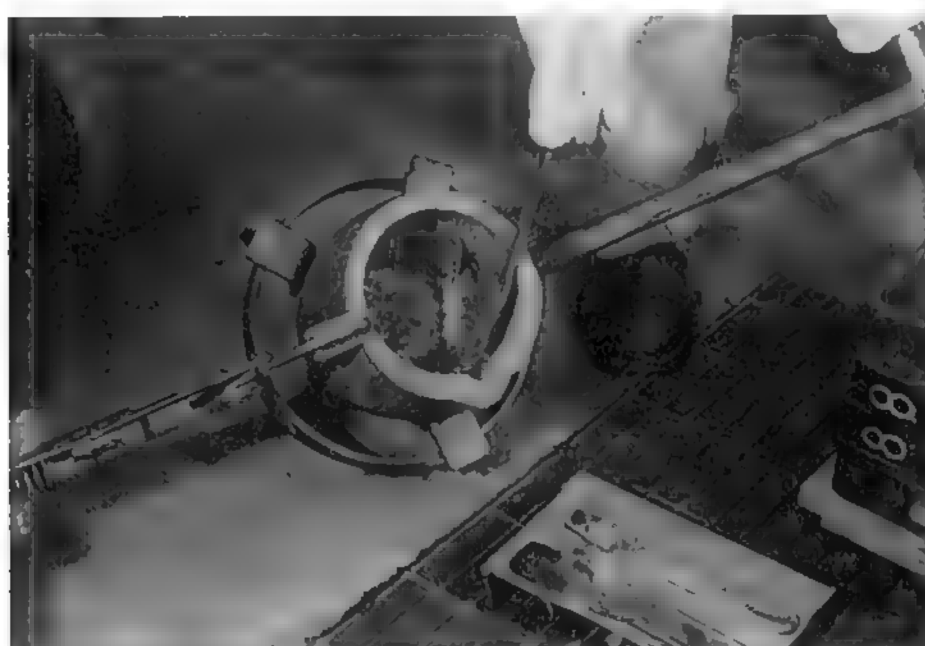


Figure 6-29
Shortly after emptying, the inside of the crucible should be lightly scraped with a blunt-edged, spoon-shaped scraper.

SHAKEOUT

After pouring, molds in an industrial foundry are allowed to cool for some time before going to shakeout, where the castings are removed. Traditional shakeout equipment (Fig. 6-30) consists of large metal grates that are shaken and vibrated vigorously. The sand, weakened from the heat of the casting, collapses and falls through the grate and is transported to the muller for reconditioning. The casting(s) and flask remain on the grates. The flask is recycled to the molding stations and the casting is transported to a cooling shed, where, after cooling to room temperature, it goes to a cleaning station and on to the chip and grind department and to subsequent processing.

In the school foundry, shakeout is much less sophisticated. Generally, students can hardly wait to see if a casting is successful, and there is a tendency to open molds too soon. This can result in ruining a casting that otherwise would have been good. Take a clue from the condition of the top of the sprue. Determine if the time from pouring to solidification of the top of the sprue and wait an equal length of time to shake out small

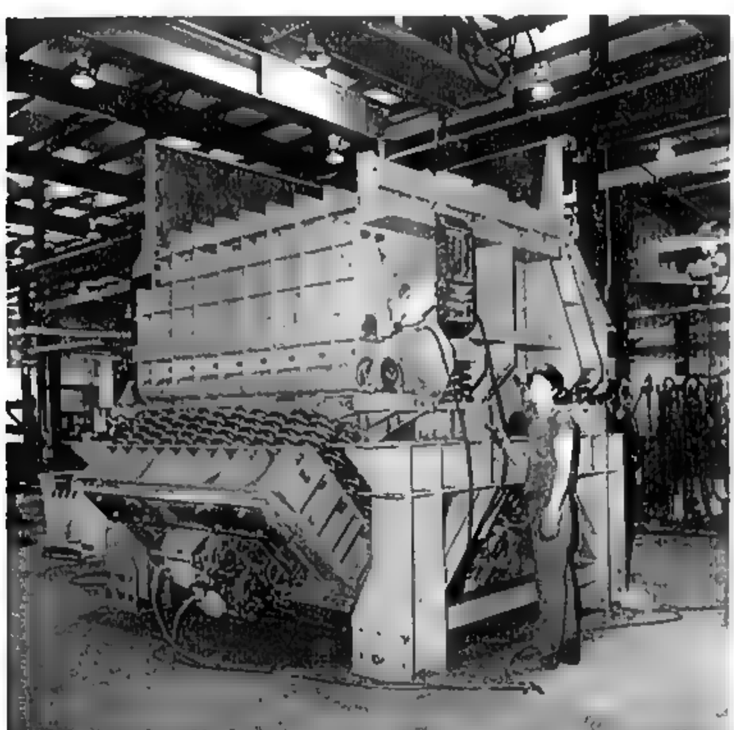


Figure 6-30
Industrial shakeout equipment.

aluminum castings. Larger aluminum castings or castings of metals that melt at higher temperatures require an appropriate increase in the length of time before the mold is opened.

Do not open a mold by lifting off the cope. This can be dangerous. The casting usually lifts out of the drag sand with the cope, but it is not always held firmly. The casting sometimes drops out of the cope unexpectedly and burns someone or is damaged. A safer and more efficient shakeout is achieved by turning the flask upside down and lifting the drag off. The casting can then be removed from the cope sand by grasping the runner system with pliers or tongs.

NOTE: When working with oil-tempered (waterless) sand, be especially cautious during shakeout. If molds are opened too soon, the oil in the sand catches fire and burns vigorously.

GATE REMOVAL

In industry, gates on castings are broken off or separated by sawing, abrasive cutting, flame cutting, or the air-carbon arc process. A hand hacksaw or metal-cutting bandsaw is probably the best way to separate the gating systems from castings in the school foundry.

NOTE: Teachers may want to evaluate students' castings *before* the gating system is removed. Although a completely successful casting is the prime objective, some evidence of partially successful castings often exists in the gating system.

Breaking off gates is not recommended unless the gates have been specially designed to be broken off. In removing gates, be sure to leave enough metal on the casting to permit filing or other cleanup operations that result in a complete casting that is not undersize at the gates.

FINISHING

A number of processes can be used to finish a casting. Gray iron castings made in industry are commonly shot-blasted or tumbled to remove sand and produce a uniform surface appearance.

Some school foundries have sandblasting equipment or a wire wheel power buffer that can produce similar results, especially on nonferrous castings. A procedure that results in an attractive product for certain castings is to sandblast the entire casting and then sand raised surfaces with very fine abrasive cloth or paper. This produces an attractive two-tone effect.

Nonferrous castings can be polished by using increasingly finer abrasive cloth and then a cloth buffing wheel with emery, tripoli, or red or white rouge as polishing compounds.

Castings can be cleaned and then painted. The availability of paint and lacquer in aerosol cans makes this a popular method.

There are a number of chemical solutions that can be used to provide an oxidized patina (colored coating) on copper-base alloy castings. Most of the ingredients for these solutions can be found in drugstores or the school chemistry laboratory.

Antique green	3 quarts water, 2 ounces salammoniac, 6 ounces ammonia carbonate
Golden bronze	1 quart sulphuric acid, 1½ pounds potassium nitrate, ¼ pint nitric acid, ¼ pint hydrochloric acid
Red to brown	1 gallon water, 1 pound iron nitrate, 1 pound sodium hyposulphite
Blue-black to black	1 gallon hot water, 4 ounces potassium sulphide (liver of sulfur), 1 ounce ammonia

The general procedure for using the above chemical solutions is to clean the article thoroughly with soap and water. Suspend the article in the solution with a *copper* wire. Remove occasionally to determine when the desired color has been achieved. Rinse in cold running water to stop the oxidizing action of the solution. Dry with air. Do not touch with bare hands until a lacquer coating has been applied.

NOTE: Be sure to use rubber gloves and to work in an area where ventilation is good when using oxidizing solutions. Also, when mixing solutions containing acid(s), always add the acid to the water.

TEST YOUR KNOWLEDGE

1. The vertical furnace commonly used for melting gray iron fueled with coke and an air blast is known as a ________.

2. Electric current, coil, magnetic fields, induced voltage, and metal resistance to current flow are features of an ________ furnace.

T-F 3. The crucible furnace is seldom used for melting iron in industry.

T-F 4. If oil-tempered (waterless) sand is used for molding, adequate venting of the pouring area is especially important.

5. The recommended atmosphere for a crucible furnace is 0.5 percent (slightly reducing, slightly oxidizing).

6. The working capacity of a No. 10 crucible is __________ pounds of aluminum and __________ pounds of red brass.

7. Crucibles most commonly used in school foundries are made of __________ graphite.

T-F 8. All pyrometers are of the immersion type.

9. Molten aluminum is treated by pushing a degasser tablet to the bottom of a melt with a __________.

10. Crucible tongs are made to fit (one, various) size(s) of crucible.

11. Crucibles are placed in __________ for pouring.

T-F 12. Crucible shanks can be either adjustable or nonadjustable.

13. Wire, sheet, bar, tubing, bolts, and so on are considered __________ metal.

T-F 14. Wrought aluminum scrap can be successfully alloyed for sand casting by adding an equal weight of *zinc,* die-cast (*pot metal*) scrap to the melt.

T-F 15. Information for using molten metal treatment products is sufficiently general that directions supplied by *one* manufacturer could be followed when using materials produced by another manufacturer.

16. Degassing of aluminum should not be done until the temperature __________.

17. With the cover fluxes described in this book, two additions of flux are made when melting __________, and one addition is made when melting __________ __________ alloys.

T-F 18. When pouring a number of molds, pour the thinnest castings first.

T-F 19. Unless specially designed gates exist, gates on school foundry castings should *not* be broken off.

20. When working with chemical solutions to color castings of copper-base alloys, be sure to use __________ __________ and work in a well-ventilated area.

CHAPTER 7

Casting Defects

Blows • Burn In • Burn On • Cold Shut • Cuts and Washes • Drops • Dross or Slag • Expansion Defects (Rat Tails, Buckles, Expansion Scabs) • Hot Tears • Misrun • Pinholes (Porosity) • Rough Surface • Sand Holes • Shrinkage (Shrink)

CHAPTER GOALS

After studying this chapter, you should be able to:

1. Explain how a casting might have one or more defects and still be a useful casting rather than a scrap casting.
2. Describe the relationship between scrap produced by a company and the company's profits and employee benefits.
3. Name and describe at least six different casting defects.

TERMS TO KNOW (see Glossary)

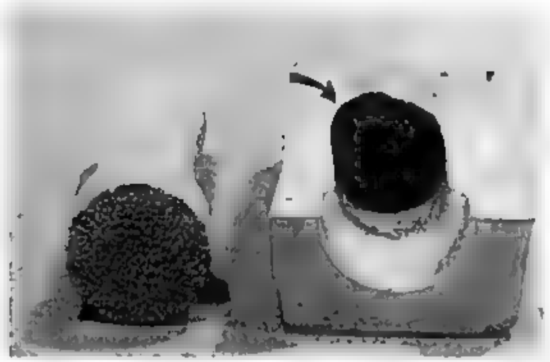
- Blows
- Burn in
- Burn on
- Cold shut
- Cuts and washes
- Drops
- Dross or slag
- Expansion defects
  - Rat tails
  - Buckles
  - Expansion scabs
- Hot tears
- Misrun
- Pinholes (porosity)
- Rough surface
- Sand holes
- Shrinkage

Metalcasters try to produce perfect castings. Few castings, however, are *completely* free of defects. Modern foundries have sophisticated inspection equipment that can detect small differences in size and a wide variety of external and even internal defects. Whether a specific defect results in a casting's being scrapped depends on the intended use of the casting. For example, slight shrinkage on the back of a decorative wall plaque is acceptable, whereas similar shrinkage on a piston cannot be tolerated. No matter what the intended use, however, the goal of modern foundries is zero defects in all castings.

Scrap castings cause much concern. In industry, scrap results in smaller profits for the company and ultimately affects individual wages. Scrap meetings are held daily. Managers of all the major departments attend these meetings. They gather around castings that have been identified as scrap by an inspector. The defect(s) is circled with chalk. An effort is made to analyze the cause of the defect, and the manager whose department was responsible for it is directed to take corrective action to eliminate that specific defect in future castings.

Most castings made in a school foundry are not subject to such rigorous examination. However, you will know when you have made a scrap casting. Usually you will be very interested in attempting to determine what caused the defect and what can be done to eliminate it in further work. Such analysis requires that you function as a detective in solving a case. There are so many variables in the production of a metalcasting that the cause is often a combination of several factors rather than a single one. All pertinent data related to the production of the casting (sand and core properties, pouring temperature, etc.) must be known in order to identify the defect correctly. After the defect is identified, you should attempt to eliminate the defect by taking appropriate corrective action. Sometimes it is important to make only *one* change at a time to the molding process so that you can see the effect of each change.

What follows are some of the more common casting defects associated with castings made in green sand molds. Defects that occur primarily with higher-temperature metals (those not commonly used in a school foundry) are marked with an asterisk(*). Appropriate remedial action is usually obvious. For example, if the defect is caused by pouring metal at too low a temperature, the obvious remedial action is to pour hotter metal. When remedial action is not obvious, appropriate suggestions are included.



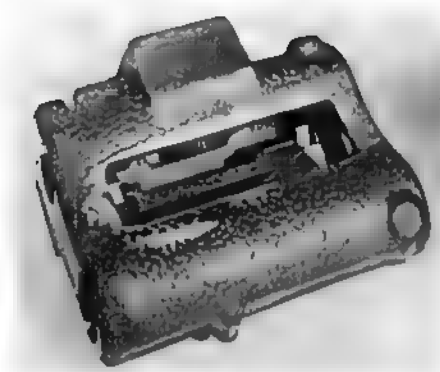
DEFECT: Blows

DESCRIPTION:

Blows occur when gases that are generated by pouring molten metal into a moist sand mold have no other means of escape than through the metal of the casting prior to its solidification. They appear as irregular or round cavities with smooth or rough walls. Sometimes it is very difficult to determine if a defect is a blow or a shrink. Improperly vented or damp cores are prone to cause blows. Figure 7-1 shows a core blow.

POSSIBLE CAUSES:

- Insufficient venting
- Insufficient permeability of sand
- Mold rammed too hard
- Core not completely dry or cured
- Sand too moist
- Local wet spots where a mold was repaired
- Core binder content too high



DEFECT: Burn In*

DESCRIPTION:

Burn in occurs when a thin layer of sand has fused with the metal surface of the casting to form a vitreous (glasslike) and possibly pockmarked surface. This defect occurs most often at hot spots in the mold surface.

POSSIBLE CAUSES:

- Excessive pouring temperature
- Excessive moisture in the sand
- Incorrectly designed gates and risers that produce hot spots in the sand
- Insufficiently large fillets at inside corners of pattern
- Thin sand section surrounded by thick metal sections

DEFECT: Burn On

DESCRIPTION:

Burn on is a defect wherein a crust of sand adheres tightly to the casting. Generally the sand cannot be removed by blast cleaning but must be ground away. This defect occurs most often at hot spots in the mold surface.

POSSIBLE CAUSES:

- Excessive pouring temperature
- Mold rammed too lightly
- Poor gating (metal not distributed evenly into mold cavity)

DEFECT: Cold Shut

DESCRIPTION:

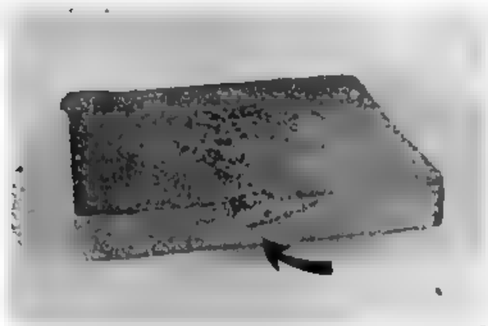
A **cold shut** is the result of two streams of metal coming together but fusing imperfectly, so that where they joined is quite obvious.

POSSIBLE CAUSES:

- Poorly designed gating system resulting in uneven metal distribution into mold cavity
- Metal too cold
- Interruption of pour
- Moisture content of sand too high
- Sand rammed too hard
- Insufficient vents or low permeability, resulting in trapped gas
- Insufficient fluidity of metal[1]

RECOMMENDED CORRECTIVE ACTION:

[1]If the casting is of aluminum, use an alloy with a higher percentage of silicon to improve fluidity. If the casting is of yellow or red brass, use phos-copper shot to increase fluidity.



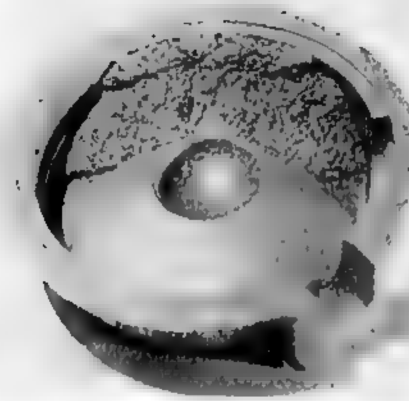
DEFECT: Cuts and Washes

DESCRIPTION:

Cuts and washes occur when the shape of a mold cavity is changed due to erosion by streams of molten metal flowing in to fill the cavity. Cutting or washing that occurs upstream from the mold cavity may result in sand from the gating system being carried into the mold cavity causing sand inclusions in the casting.

POSSIBLE CAUSES:

- Sand too dry
- Mold rammed too lightly
- Insufficient bond in sand mixture
- Patterns with insufficient draft, so that sand collapses when the pattern is withdrawn
- Sand not mulled long enough
- Poorly designed gating system, causing metal to flow through gating system and enter mold at high velocity



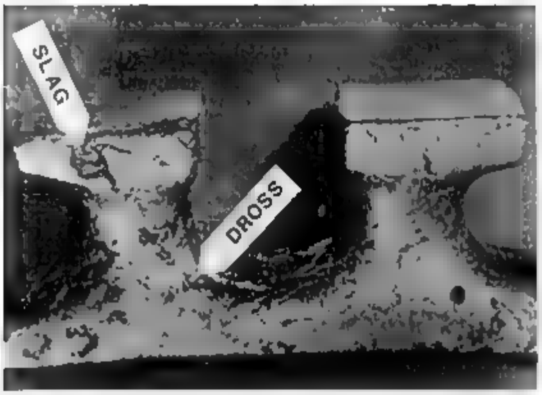
DEFECT: Drops

DESCRIPTION:

A **drop** occurs when chunks of sand from the cope fall into the mold cavity, preventing metal from filling the mold. Some rather unusual scrap castings result.

POSSIBLE CAUSES:

- Sand too dry
- Insufficient bond in sand mixture
- Mold rammed too lightly
- Accumulation of excessive fines (grains of sand much smaller than the basic grain size of the molding sand) in sand mixture
- Rough handling of molds



DEFECT: Dross or Slag in the Casting*

DESCRIPTION:

Dross or **slag** in the casting is an easily recognizable defect. Even the most careful skimming will not produce castings free of defects if the gating system is poorly designed. However, the first metal down the sprue is inevitably damaged and the gating system should provide some means for this damaged metal to remain in the gating system rather than entering the mold cavity and becoming a part of the casting.

POSSIBLE CAUSES:

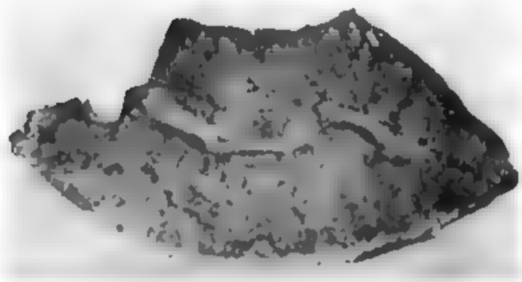
- Metal not skimmed with sufficient care
- Improperly designed gating system—using direct gating (rather than using runners in the drag and gates in the cope) results in a mold that automatically becomes a slag trap
- No or insufficient runner extension or sump
- Poor melting practice—using "dirty" metal

Expansion defect: rat tails.

EXPANSION DEFECTS: Rat Tails, Buckles, Expansion Scabs*

DESCRIPTION:

Rat tails are shallow, irregular grooves in the surface of the casting, often near a gate, and usually at the drag surface. Heat from the molten metal entering the mold causes condensation, expansion, and buckling of a thin sand crust. The edges of this crust extend inward. The metal flowing against these edges forms the grooves known as rat tails.



Expansion defect: buckles.

DESCRIPTION:

Buckles are V-shaped indentations that can occur on all surfaces but are normally found on horizontal cope and drag surfaces. The heat from the molten metal causes the sand to expand and the mold wall to distort inwardly and fracture with the metal flowing only into the line of fracture, not under the sand.

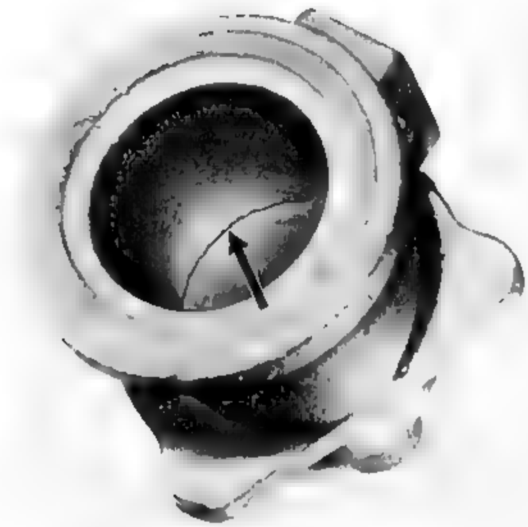
Expansion defect: expansion scabs.

DESCRIPTION:

Expansion scabs are thin, irregular, sharp-edged metallic projections, parallel to the surface of a casting and attached to it at only a few points. They are formed in much the same way as buckles, except that molten metal flows through the line of fracture and *under* the crust of sand. Expansion scabs can be removed with a fingernail or knife.

POSSIBLE CAUSES:

- Metal poured too slowly
- Sand too wet
- Mold rammed too hard
- Excessive fines in the system sand
- Insufficient clay content
- Poorly or improperly mulled sand
- Poor gating system



DEFECT: Hot Tears*

DESCRIPTION:

A **hot tear** (crack) may develop in a casting as the metal solidifies if the mold does not give; it can also occur if the mold is opened before metal has completely solidified.

NOTE: It is not likely that this defect will occur very often in the school foundry, where castings tend to be small and the molds not nearly as dense as those in industry, unless the defect is caused by opening the mold too soon.

POSSIBLE CAUSES:

- Mold too dense with insufficient collapsibility
- Fillets too small
- Casting shaken out too soon
- If aluminum, the alloy being used is prone to hot shortness (brittleness at high temperatures)
- Poor casting design

DEFECT: Misrun

DESCRIPTION:

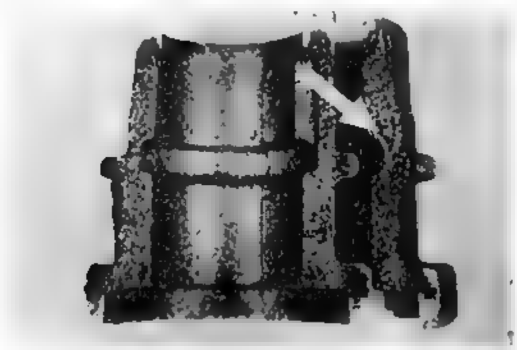
A **misrun** is an incomplete casting resulting from a mold cavity (that is free of defects) not being filled with molten metal. If the leading edge of a misrun is concave, trapped gas is indicated. If the leading edge is convex, cold metal or slow pouring is the probable cause.

POSSIBLE CAUSES:

- Metal poured too slowly
- Metal poured too cold
- Insufficient head[1]
- Choke or gates too small
- Metal chilled prematurely by excessive moisture in sand
- Low permeability of sand
- Insufficient fluidity of alloy being used

RECOMMENDED CORRECTIVE ACTION:

[1]Increase sprue height.



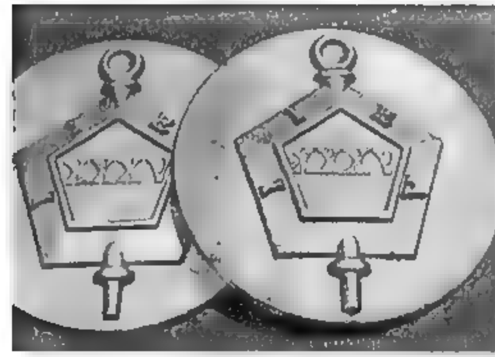
DEFECT: Pinholes (Porosity)

DESCRIPTION:

Pinholes are small, angular or round holes that appear on the cope surface of the casting (rather than the drag surface, where similar holes are made by loose sand). Sectioning often shows porosity throughout the casting. Do not confuse pinholes with microshrinkage.

POSSIBLE CAUSES:

- Metal not properly degassed before pouring
- Excessive turbulence during pouring
- Metal too hot when poured
- Sand too wet
- Inadequate venting of mold
- Too little head pressure (increase height of sprue and pouring basin)



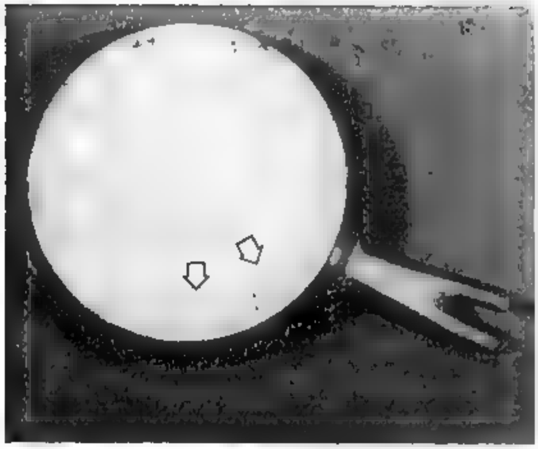
DEFECT: Rough Surface

DESCRIPTION:

As shown above, the "as-cast" surface is rougher than expected or desired.

POSSIBLE CAUSES:

- Pattern not completely clean
- Facing sand not riddled
- Mold rammed too lightly
- Too much dry parting agent used
- Metal too hot
- Molding sand too wet
- Head pressure too high



DEFECT: Sand Holes

DESCRIPTION:

Sand holes result from the presence of loose sand somewhere within the mold. The holes often contain sand grains and, in the case of aluminum alloys, are found in the drag surface of the casting.

POSSIBLE CAUSES:

- Loose sand not removed from mold before closing
- Thin edges of sand in mold cavity being washed from original position; or, in gating system, being washed into mold cavity
- Moisture of sand too low
- Sand rammed too lightly
- Green strength of sand too low
- Sand not mulled long enough

DEFECT: Shrinkage (Shrink)

DESCRIPTION:

Shrinkage (shrink) is an undesired depression on the cope or side surface of the casting. A granular appearance is usually evident in the depression. (A shrink can occur internally, too. In addition, some alloys, such as aluminum, are also prone to microshrinkage, which is sometimes incorrectly labeled "porosity" or "pinholes.")

POSSIBLE CAUSES:

- Gating into thin rather than thick sections
- No riser to feed thick sections
- Risers too small
- Risers improperly placed
- Metal too hot
- Inappropriate alloy for sand casting

TEST YOUR KNOWLEDGE

Write your answers on a separate sheet of paper. Do not write in this book.

1. The goal of modern foundries is __________ defects.
2. In industry, the higher the scrap rate, the __________ the individual wages.
3. Analyzing casting defects involves the type of work done by a __________.
4. The defect that is caused by gas attempting to escape through the metal prior to its solidification in the mold is known as __________.
5. When two or more streams of metal entering the mold cavity join, but leave evidence that they are not perfectly fused together, the defect that results is called a ______ ______.
6. Small holes appearing in the cope side of a casting are __________; similar holes on the drag side are ______ ______.
7. An incomplete casting that results from a good mold cavity not being filled with molten metal is called a __________.
8. An undesired depression on the cope surface of a casting is known as __________.

CHAPTER 8

Innovative Metalcasting Processes

Permanent Mold Casting • Die Casting • Shell Molding • Investment Casting • Lost Foam Process • V-process • H-process • CLAS Process

CHAPTER GOALS

After studying this chapter, you should be able to:

1. Name two innovative metalcasting processes that use the same mold over and over to produce additional castings, and two innovative metalcasting processes that require new molds to be made for each casting.
2. Explain how semipermanent mold casting differs from permanent mold casting and how both processes differ from low-pressure permanent mold casting.
3. Explain how hot-chamber die casting machines differ from cold-chamber die casting machines.
4. Describe how investment in shell molding differs from investment in the lost wax process.
5. Identify at least two innovative metalcasting processes that, because they don't require a lot of equipment, are suitable for instruction in the school foundry.
6. Identify at least two innovative metalcasting processes that, because they require rather extensive equipment, are not as suitable for instruction in the school foundry.
7. Identify two innovative metalcasting processes in which castings are made in loose, free-flowing, unbonded sand.
8. State the principle that governs the selection of material to be used to pry a stuck part from a mold.

9. Explain the different ways in which investment and lost-foam patterns are used and destroyed.
10. Identify at least two innovative metalcasting processes in which zero draft is possible.
11. Point out the main difference between the cavityless casting process and the full mold process.
12. Explain why the refractory coating applied to a lost-foam pattern need not be smooth as is the case when we paint an article.
13. Describe how the cavities in CLAS process molds are filled with metal.

TERMS TO KNOW (see Glossary)

CLAS process
Permanent mold casting
Gravity-die casting
Static pour operation
Semi-permanent mold casting
Low-pressure permanent mold casting
Die casting
Hot-chamber die casting machine
Cold-chamber die casting machine
Shot sleeve
Single cavity die
Multiple cavity die
Combination die
Assembly
Unit die
Shell molding
Investment time
Cure time
Lost wax process
Investment casting
Investment flask casting
Investment shell casting
Button
Shock heating
Lost foam process
Cavityless casting
Full mold process
Static head
V-process
H-process
Yield
Runner sphere
Well
Weir
Slag trap
Drag ingates

The first seven chapters in this book are devoted almost exclusively to the production of metal castings in green sand molds. This is appropriate since green sand molds produce the greatest tonnage of metal castings. However, there are several other processes by which metal castings are produced. These could be called innovative metalcasting processes, since at the time each was introduced, it was new and quite different from green sand molding and other metalcasting processes then in use. All these processes have certain advantages (and disadvantages) when compared with green sand molding.

Many of these processes can be carried out in the school foundry, and important concepts can be learned in spite of the unsophisticated equipment that may be used. None of these metalcasting processes is of sufficient importance to replace fundamental instruction in green sand molding, but any of them (the more, the better) can be used to enrich a school foundry program.

This chapter covers eight innovative metalcasting processes that are important industrially. Seven of them can be carried out successfully in the school foundry. The eighth process, the **CLAS process**, is the most recent and one of the most imaginative of the innovative metalcasting processes. Limited information about this fascinating process is provided at the end of this chapter.

PERMANENT MOLD CASTING

As you know, green sand molds are used only once. Metal is poured into them, and after it has solidified, the sand mold is broken up to remove the casting. The sand is recycled and used to make other molds. In **permanent mold casting** (sometimes called **gravity-die casting,** since the poured metal is under only atmospheric pressure) the molds are made of metal (or, in certain applications, graphite). The molds are designed so they can be *opened* to remove the casting. This enables the mold to be used again and again. Permanent, in this case, doesn't mean forever. Each time the mold is used to make a casting, a very small amount of wear (deterioration) takes place. Even so, the mold may be used to make many thousands of castings before it needs to be replaced.

Molds used in this process can be highly sophisticated with such fea-

tures as ejector pins, sliding core pins, water cooling, and so on, or they can be very simple. Although several different materials, such as steel, copper, and aluminum, are used to make the molds for this process, gray iron is most commonly used. Permanent mold castings have been produced from a great variety of both nonferrous and ferrous alloys. Aluminum (nonferrous) and ferritic iron (ferrous) are most used in their respective categories.

A suitable mold coating is required. The coating serves several important purposes. It insulates the poured metal from the chilling effects of the metal mold so that the mold can fill completely. It also isolates the poured metal from the surface of the mold, greatly reducing its erosion, checking (development of tiny cracks), and other damage to the mold. The mold coating assists in venting the mold and serves as a lubricant, making it easier to release the casting from the mold. A number of proprietary mold-coating materials have been developed. Most are liquids that are sprayed on the mold cavity surface.

Advantages and Disadvantages

In comparison with green sand molding, permanent mold casting has a number of advantages and disadvantages. Some of the advantages are

- The rapid cooling of the metal mold produces sound, dense castings that have excellent mechanical properties.
- Metal molds produce castings with very high dimensional accuracy.
- The high dimensional accuracy achieved with permanent mold casting reduces the need for machining.
- Metal molds provide finishes of consistent quality.
- The working environment is cleaner and quieter than that in a green sand foundry.

Disadvantages of the permanent mold casting process include

- Metal molds are expensive, so the number of castings necessary to justify the cost is high.
- Changing and repairing the tooling is time-consuming and expensive.
- The rapid cooling of the poured metal by the mold makes thin sections problematic.

Permanent mold casting in industry can be a relatively simple operation as is the case with a **static pour operation,** where the mold is in a vertical position throughout the casting process and is filled by hand

ladling. The process can also be a quite sophisticated **tilt pour operation.** Figure 8-1 shows a rotary machine with molds at each of eight stations. At station 1, the mold is sprayed with mold coating and closed. At station 2, an automatic ladle fills the pour cup and the mold starts to tilt at a programmed rate. The casting cools as the machine rotates until it arrives at the station 8, where the mold opens and the casting is picked out of the mold by a robot and transferred to a conveyer belt where it will be taken to other work stations for gate removal and additional processing.

If sand cores (rather than metal inserts) are used to produce holes and internal passageways, the process becomes known as **semipermanent mold casting.**

Another, similar process should be mentioned: **low-pressure permanent mold casting** is neither permanent mold casting nor **die casting** (where metal is injected at high pressure into the mold), but has important elements of both and falls between the two. This process uses a metal mold that is clamped in a press above a *sealed* furnace that contains molten metal. A metal fill tube extends from below the surface of the metal to the mold. A small amount of air pressure, applied to the surface of the metal, forces metal up the fill tube and into the mold. After solidification, the mold is opened and the casting(s) removed.

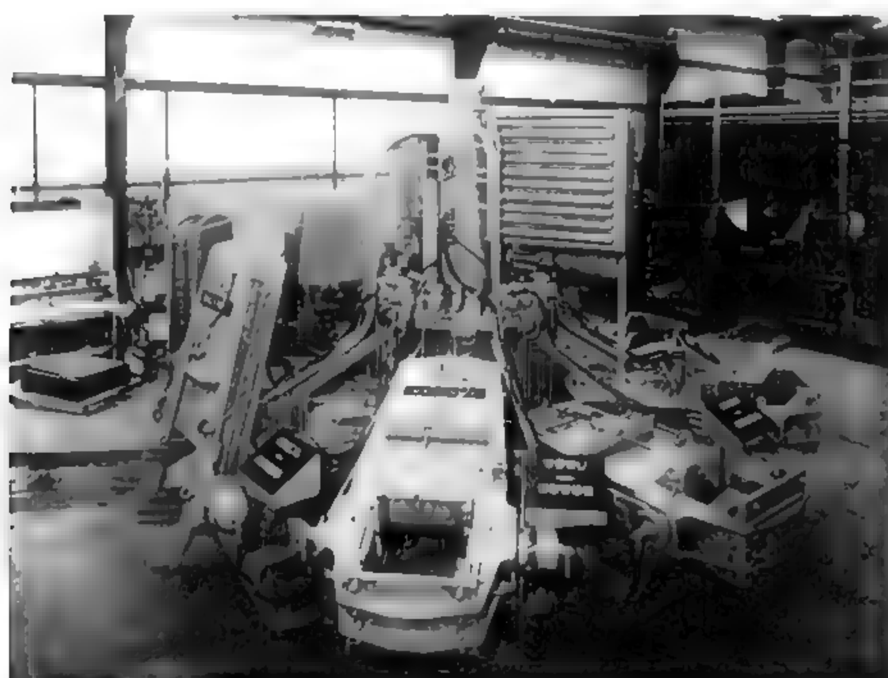


Figure 8-1
An eight-station, rotary permanent mold machine.

In the school foundry, important concepts about permanent mold casting can be learned with very simple equipment. Pouring lead into aluminum sinker molds is a permanent mold activity that can be carried out with little expenditure of time or money. Somewhat more sophisticated equipment can be built by advanced students. The following procedure for permanent mold casting involves just such equipment (Fig. 8-2).

Procedure

1. Begin the melting procedure. Be sure to use an aluminum alloy appropriate for permanent mold casting, such as 238, 333, or 354. If scrap metal is used, aluminum pistons work well.
2. Preheat the mold, if necessary, with an oxyacetylene torch and large tip. Use a surface pyrometer or temperature-indicating crayon to determine when the proper temperature has been reached—500–800F (260–430C) for aluminum. A preheat of 250F (120C) is sufficient for zinc.

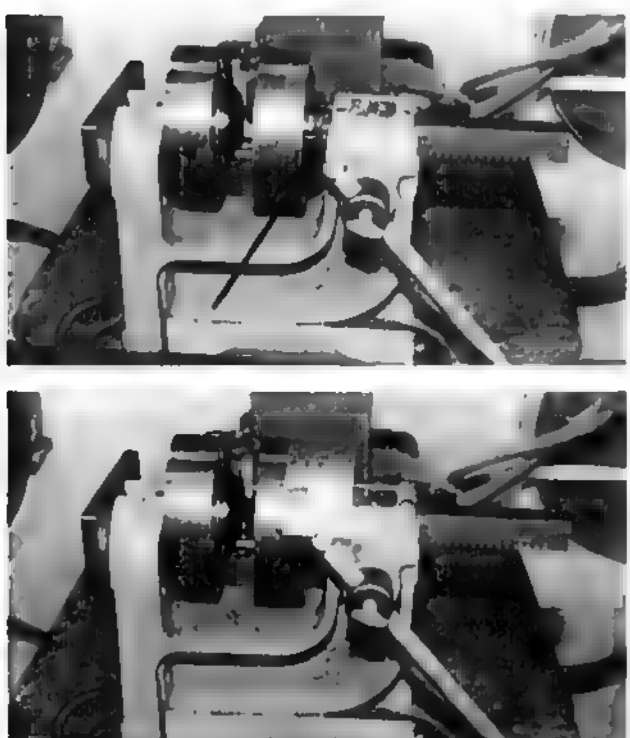


Figure 8-2
Top: Home-made permanent mold machine. Dies are mounted to a small arbor press laid on its back. Notice the ejector pins (*arrow*). *Bottom:* A shield mounted to protect the springs on the ejector pins from accidental spills.

NOTE: Operating temperatures are usually determined by trial and observation. Just enough preheating is needed so that the molten metal will not freeze before filling the cavity. When this temperature is achieved, it can be *maintained* by the heat of the metal poured into the mold and by *varying* the cycle time.

3. Apply mold coating (if necessary) in the form of carbon from a reducing oxyacetylene flame (Fig. 8-3).
4. Close the mold halves together very tightly.
5. At 1275F or 690C (or the temperature determined by trial and observation to work best) pour the molten metal into the mold (Fig. 8-4).
6. Allow the casting to solidify and cool to about 800F or 430C.

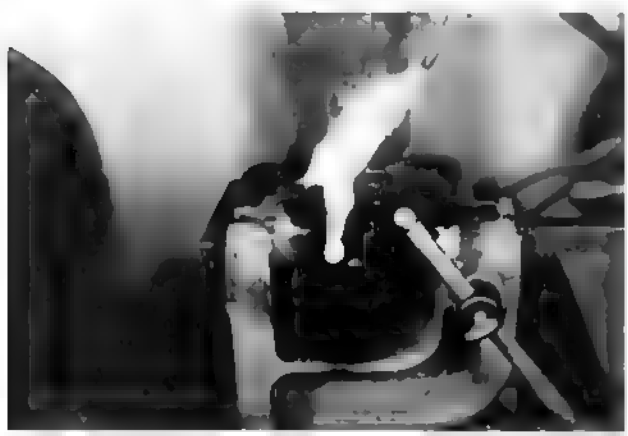


Figure 8-3
An oxyacetylene torch, burning only acetylene, can be used to coat the surfaces of the die with carbon, which will help to release the casting from the mold.

Figure 8-4
Pouring the mold.

Figure 8-5
Removing the casting.

7. Open the mold.
8. Remove the casting. If the equipment has ejector pins it may be necessary to catch the hot casting before it drops out of the mold and is, perhaps, damaged. Use heat resistant gloves or pliers *gripping the gating system* (Fig. 8-5).

NOTE: If a casting becomes stuck in a mold, a material *softer* than the mold material must be used to pry or dislodge the casting or the mold will be damaged. A brass rod works well for iron and steel molds.

9. Allow the casting to cool.
10. Return all permanent mold equipment, articles, tools and equipment to their proper places.
11. Remove the gating system.

DIE CASTING

Die casting is the fastest way of producing metal castings, and is a very important part of the cast-metals industry. If you have prepared foundry sand, made a mold, melted metal, poured the mold, and waited the nec-

essary time before shaking out the casting, you know that it is difficult to produce a metal casting in a green sand mold in less than 1 hour. Many die casting machines complete a full cycle in one minute or less. The die casting process is similar to permanent mold casting in that metal molds (or dies) are used. An important difference, however, is that in die casting, the molten metal is *forced into the die with pressure.* There are two types of die casting machines.

In a **hot-chamber die casting machine,** the injection mechanism is *immersed* in molten metal (Fig. 8-6). Such machines are used primarily to produce castings of zinc alloys and other alloys that have low melting points. The machines are very fast, some cycles being as short as 10 seconds. Thus, a four-cavity die can produce 24 castings in a minute. **Cold-chamber die casting machines** have a **shot sleeve,** into which molten metal is poured (Fig. 8-7). A hydraulic cylinder moves a plunger that forces the metal into the die at pressures of 3,000–15,000 pounds per square inch. Although somewhat slower than hot-chamber machines, cold-chamber machines are able to produce die castings of materials with higher melting points, such as aluminum, magnesium, and copper-base alloys.

Low-melting-point alloys (less than 725F [385C]) such as zinc and tin are usually cast in non–heat-treated carbon steel molds in hot-chamber

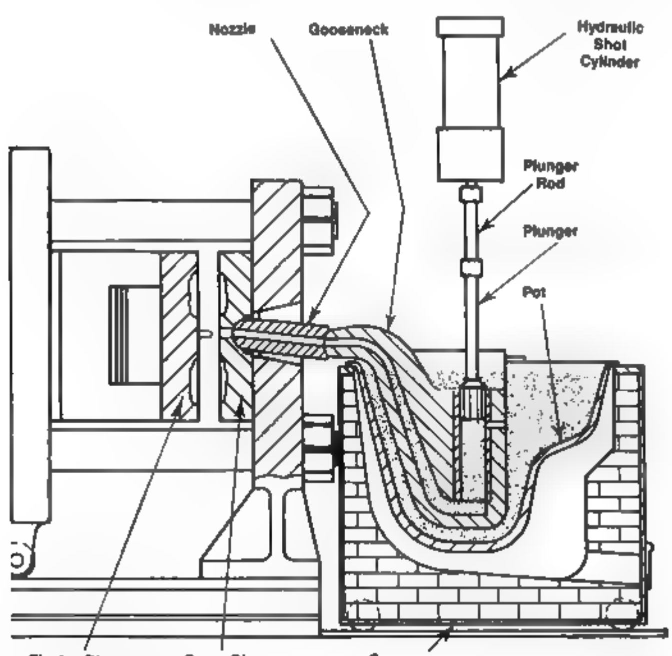


Figure 8-6

Sectional view of a hot-chamber die casting machine. Note the plunger mechanism is *submerged* in molten metal.

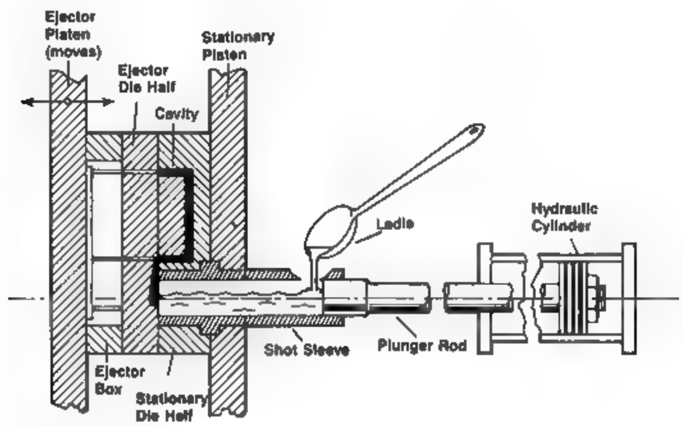


Figure 8-7
Sectional view of a cold-chamber die-casting machine. After the molten metal is poured into the shot sleeve, the plunger forces it into the die cavity.

machines. Medium–melting point alloys (1150–1300F [621–704C]) such as alloys of aluminum and magnesium are commonly cast in low-alloy, heat-treated molds in cold-chamber machines. High-melting-point alloys (over 1650F [899C]) such as copper-base alloys are cast in special alloy, heat-treated molds in cold-chamber machines. The very high temperatures required for ferrous metals limit their use in die casting to experimental rather than production work.

Many dies are designed as **single-cavity** or **multiple-cavity** dies. **Combination dies** produce several parts that later make up an **assembly,** (Fig. 8-8). There are also **unit dies,** which are used to reduce tooling or production costs. Unit dies are assembled in a unit holder. A common sprue and runners align with the gates of both units (Fig. 8-9). In this way, several parts (for one assembly or for different customers) can be cast at the same time.

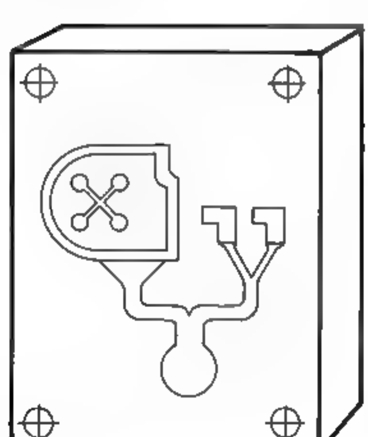


Figure 8-8
A combination die is used to produce parts needed for an assembly.

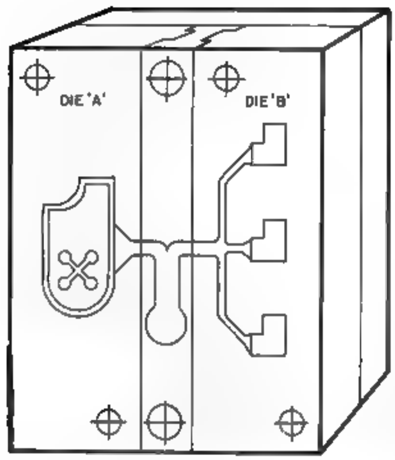


Figure 8-9
A unit die permits several cavities to be assembled on a common holder. Producing several different parts either for the same assembly or for different customers, can reduce production costs.

At the beginning of each cycle, the dies are sprayed manually or automatically. This spray lubricates the dies and facilitates the removal of the castings after solidification. It also helps to cool the die and maintain a proper working temperature.

Advantages and Disadvantages

In comparison with green sand molding, the die casting process has a number of advantages and disadvantages. Some of the advantages include

- The process is much faster.
- Shapes can be more complex.
- Closer tolerances can be achieved.
- Smoother (or even-textured) surfaces are usually produced.
- Thinner walled castings can be produced.
- External threads can be produced in casting rather than by a subsequent operation.
- Castings straight from the die require little or no machining.
- Thousands of castings can be produced before original tooling must be replaced.
- The working environment is cleaner.

The disadvantages of die casting include

- The size of castings is limited. A 20-inch aluminum BMX bike wheel weighing 3½ pounds is a *large* die casting. Larger castings in-

volving greater volumes of metal require huge machines with tons of die-locking force.

- Die casting machines are very expensive.
- The tooling (dies) used on the machines is also quite expensive.
- The die casting of ferrous alloys is still considered developmental or experimental.

Modern die casting machines are very sophisticated. Recently, a *vertical* die casting machine, which uses much less floor space and claims other important advantages, has been developed. However, most machines in present use are horizontal. The size of a machine is expressed in tons of clamping force and shot size (maximum weight of metal that can be cast at one time). Cold-chamber machines range from 100–3600 tons in size. Shot sizes range from several ounces in small machines to five pounds in the largest machines. Some machines are equipped with a number of automatic features, such as die sprayer, ladler, and part extractor. Some even have automatic die changers. All have an operator's console, with electronic (possibly programmable) controls.

Because of the sophistication required in a die casting machine, this process is not normally a part of the hands-on experience provided in school foundry programs. However, some school foundries possess a die casting machine designed specifically for use in an educational setting. Such a machine is shown in Fig. 8-10. It is operated by pneumatics, rather than by the hydraulics used to operate industrial-type die casting machines. This makes it a less expensive, simpler, and safer machine. In most other aspects, it functions like a production die-casting machine. Students working with a die casting machine in a school foundry should

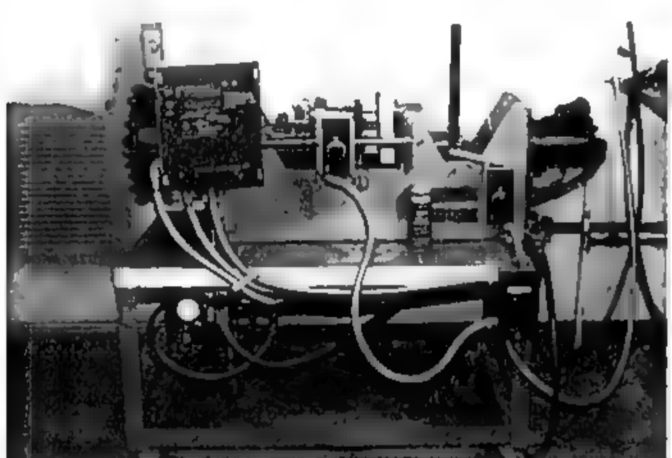


Figure 8-10
A horizontal cold-chamber die casting machine appropriate for a school foundry.

follow the specific instructions provided in the machine's operator's manual.

SHELL MOLDING

Shell molding was developed in Germany by Johannes Croning during World War II. About 9 percent of foundries in the United States were using the process by 1958. Since then, its impact has been substantial, for it is now considered one of the conventional molding processes.

Shell molding was the first of the newer mold making processes. It was a radical departure from green sand molding in that only *dry* sand was used and the mold was *thin-walled,* rather than a cavity within a solid block of molding material. The speed with which molds can be made is dramatic, and the process is easy to automate.

Briefly, the process consists of heating *metal* cope and drag patterns to 500F (260C), applying a release agent, and dumping or blowing sand coated with resin (thermosetting plastic) onto the pattern. In a relatively short time (20–30 seconds), the heat from the pattern penetrates the sand, producing a bond in the heat-affected layer. This layer clings to the pattern, and when the pattern is rotated, the sand not affected by the heat falls into the hopper for subsequent use. The thin, bonded layer of resin-coated sand (⅛–⅜ inch [3–9 millimeters], depending on casting size) clinging to the pattern is cured by heating at 550–800F (288–427C) for 1–2 minutes. The cured shell is then pushed (stripped) from the pattern by ejector pins. When a mating shell is produced, the shells (together with any required cores) are aligned (with locator pins) and fastened together with a high-temperature adhesive (or clamped together) for pouring. If the weight of the metal, the pressures developed during pouring, or safety dictates, the assembled shells are placed in a container and surrounded with steel shot, course sand or gravel. Such material provides additional support for the somewhat fragile shells. After pouring, the shells are broken away. Sometimes the sand is reclaimed for reuse.

The shell process is used in making cores as well as molds. (See Chapter 3.)

The patterns for shell molding must be metal. Aluminum and cast iron have been proven quite successful. Ejector pins and locators to help align mating mold parts are built into the patterns.

The sands most used in making shell sand are silica and zircon. Grain sizes in these sands are generally finer than in sand used in green sand molding. The sand must be clean and free of clay. Subangular sand grains (angular grains with the sharp corners rounded off) are considered superior to round or angular grains. Many foundries in the past produced their own shell sand by purchasing all the necessary ingredients and coating the sand themselves. Most foundries now purchase coated sand.

The release agent most commonly used in shell molding is silicone, readily available in aerosol cans.

Most commercial metals and alloys can be poured into shell molds successfully.

Advantages and Disadvantages

In comparison with green sand molding, shell molding has a number of advantages and disadvantages. Some of the advantages are

- Shell molds require only a small fraction of the sand used in green sand molding.
- The molds are much lighter.
- The molds are unaffected by atmospheric conditions and can be stored indefinitely.
- Shell molds have good permeability—gases can escape easily.
- The molds contain no moisture, and metal can therefore be poured at lower temperature.
- Castings from shell molds have excellent detail.
- Castings have better surface finish.
- Castings are more precise, with minimum variation in dimensions.
- The equipment requires less floor space.

The disadvantages of shell mold casting include

- The sand costs more.
- The sand is not reusable unless it is reclaimed.
- The energy required for heating patterns and curing shell molds is expensive.
- Patterns must be made of metal.
- Automatic shell molding equipment has a high initial cost.
- High production runs are needed to offset cost of pattern equipment.

Equipment for the shell mold process can be relatively simple or quite complex. All steps in the process—pattern heating, pattern cleaning, spraying the release agent, investment, curing, and stripping—are carried out in order at a single-station machine (Fig. 8-11). More sophisticated multi-station machines (Fig. 8-12) are set up like a carousel with all mold-making steps taking place at the same time at different stations.

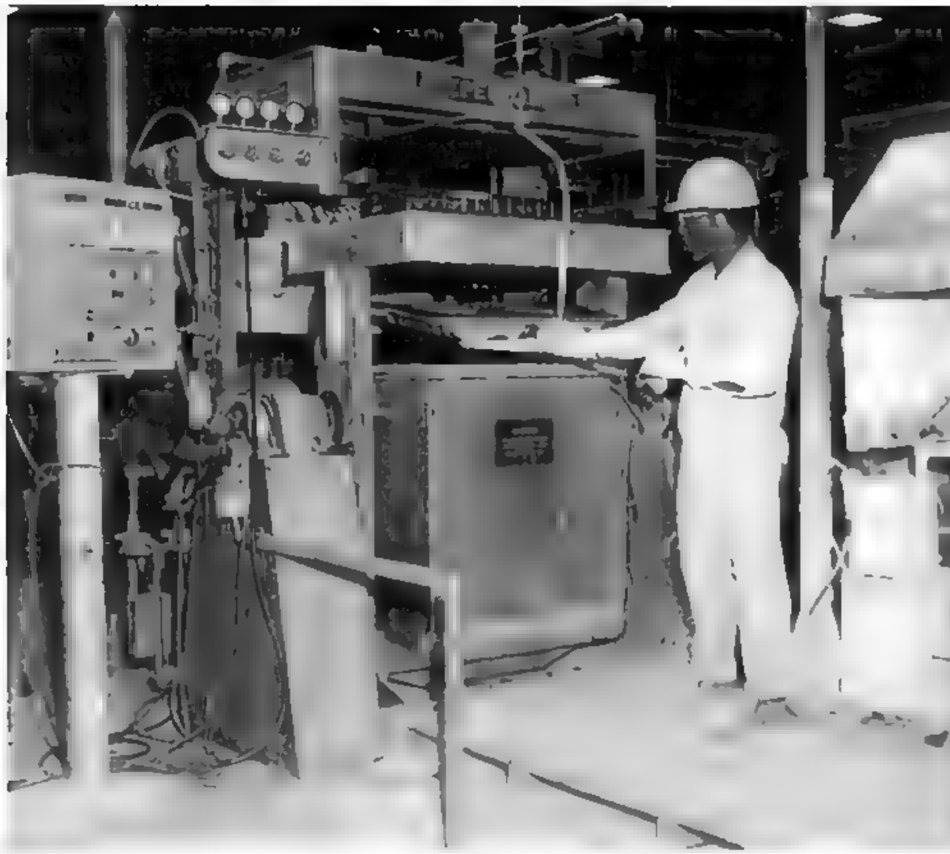


Figure 8-11
A single-station shell molding machine.

The shell molding process (as well as shell core-making) is relatively easy to carry out in a school foundry. Some special equipment is required, but none of it is expensive and much of it can be adapted or fabricated by advanced students or the teacher. The procedure for shell molding given below involves just such equipment.

1. Oven
2. Patterns
3. Resin-coated sand
4. Mold spray
5. Dump box
6. Surface pyrometer or temperature-indicating crayons
7. Ejection equipment
8. Binder clips

Figure 8-12
A multi-station shell-molding machine.

9. Pouring box
10. Gravel
11. Heat-resistant gloves

Procedure

1. Heat the patterns to 500F (260C) in the gas oven. Use a surface pyrometer (or temperature-indicating crayon) to check the temperature.

NOTE: If a gas oven is not available, the crucible furnace can be rigged up (Fig. 8-13) to heat the pattern and cure the shell.

2. Remove a pattern, spray it with mold release, and clamp it on the dump box (Fig. 8-14).
3. Roll the dump box over gently and keep it inverted for 20–30 seconds. This is called the **investment time.**
4. Roll the dump box back to its original position, remove the pattern *immediately,* and turn it over so the shell is on top (Fig. 8-15).

Figure 8-13
Pattern in place on holder with sheet metal shroud placed on furnace to direct heat.

5. Place the pattern and shell into the oven and bake for approximately 1½ minutes or until the shell is golden-brown. This is the **cure time.**
6. Remove the pattern from the oven and strip the shell from the pattern by using the special frame and press (Fig. 8-16). This will ensure that equal pressure is applied to each of the spring-loaded ejector pins.

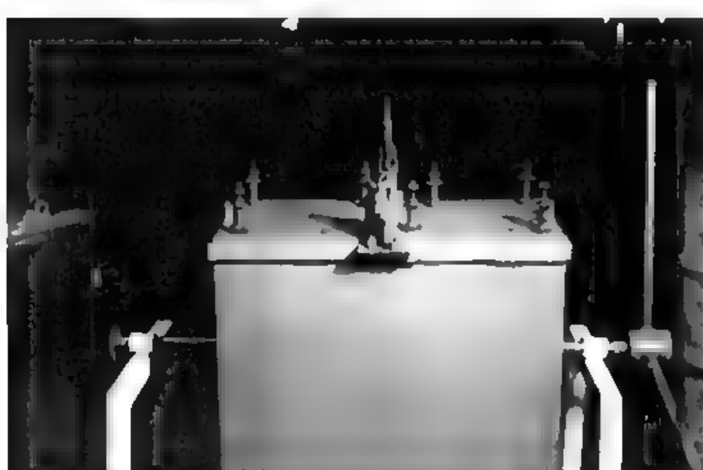


Figure 8-14
Heated pattern clamped to dump box.

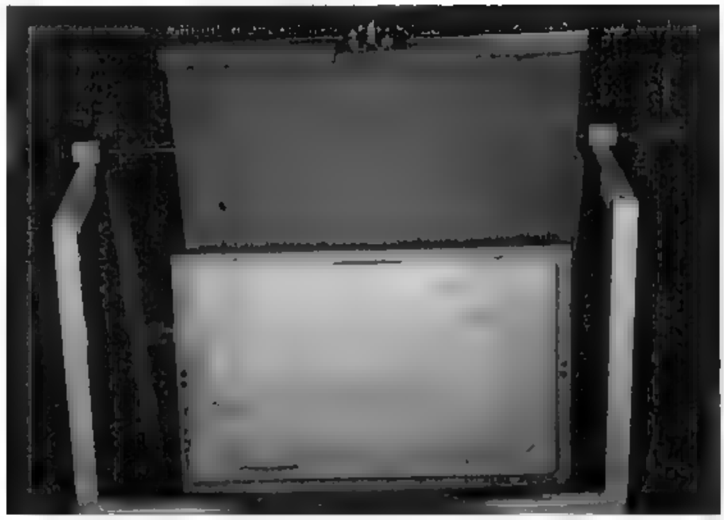


Figure 8-15
Shell mold pattern, just removed from dump box, with shell in place.

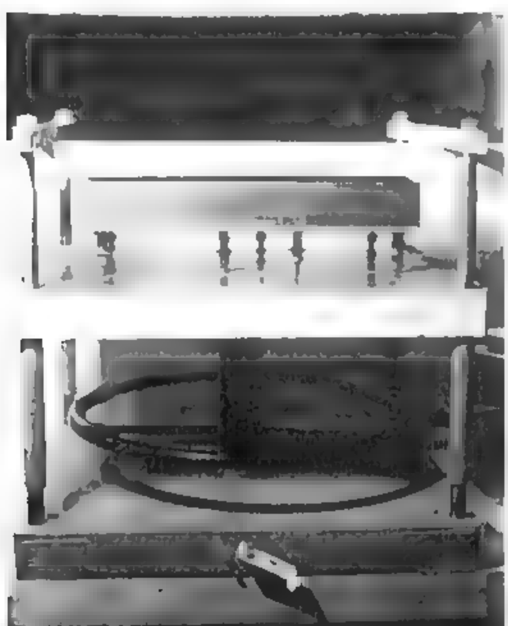


Figure 8-16
A frame has been placed around the cured shell and a 2 × 4 placed on top of the frame. As the platen is raised with the large hand wheel and the 2 × 4 contacts the cross bars, *equal* pressure on all spring loaded pins will push the shell off of the pattern.

7. Place the shell on a flat surface and weight it with a sand bag to prevent warping (Fig. 8-17).
8. Make the other half of the mold by following steps 2–7 above.
9. Fasten the two halves together with binder clips (or glue), place them in the pouring box, and back them with gravel. Cover the sprue hole while adding the backing material (Fig. 8-18).

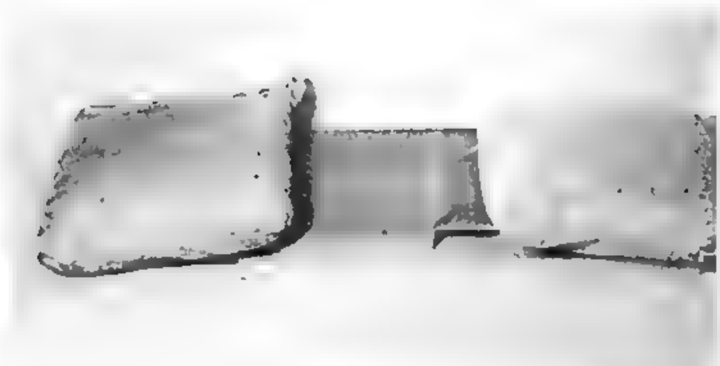


Figure 8-17
Precautions should be taken to prevent the shell from warping. Use sand bags to hold the shell against a flat surface until cool.

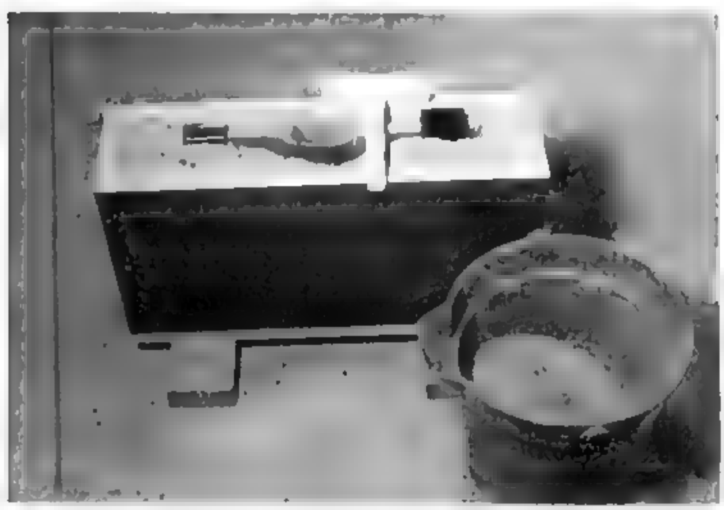


Figure 8-18
A cover made of 3- × 5-inch cards is used to prevent backing material from entering the sprue.

10. Pour the mold. Pour fast. Keep the lip of the crucible as close to the sprue as possible.
11. Allow sufficient time for solidification.
12. Move the pouring box outside the foundry area for shakeout.
13. Remove mold from pouring box and break the shell away from the casting. Discard the spent shells. Save gravel backing material for reuse.
14. Sweep up shakeout area. Return all shell molding equipment, articles, tools, and material to their proper places.

INVESTMENT CASTING

One of the earliest methods of producing metal castings was the **lost wax process.** Metal castings have been found that appear to have been made by this process 3000–4000 years ago. The lost wax process is *one* type of **investment casting.**

All investment casting processes use heat-disposable patterns: waxes, some types of plastics, or organic substances are all consumed by heat. In the lost wax process, wax patterns are surrounded with investment material (a slurry of plaster-of-paris-like material). After the investment sets (hardens), it is heated at 300F (150C) for about an hour. During this time the wax pattern will be "lost" (melt and drain out of the mold) leaving a cavity in the investment shaped precisely like the pattern. The mold is then subjected to gradually increasing temperatures up to 1350F (730C). If this process is being carried out with a plastic or organic pattern, this amount of heat will eliminate all traces of the pattern. The cavity in the mold, filled with molten metal, produces a casting identical to the pattern that was used.

The lost wax process is still used today to make one-of-a-kind metal castings. Artists meticulously fashion patterns from a variety of specialized waxes and carry out the process as described above. The process is also used a great deal in dentistry, where gold crowns are produced to fit specific teeth.

Other investment casting processes, however, are much more industrially oriented. These were developed during World War II to meet a need for precise parts for arms and aircraft that could be produced without machining, welding, or assembly. Such processes are categorized as **investment flask casting** or **investment shell casting.**

The processes are similar in all respects except for the investment step. In both procedures wax patterns are produced rapidly by injecting molten wax into a mold in a manner somewhat similar to that used when molten metal is injected to make a die casting. The individual patterns are then gated to a central sprue of wax, making a "Christmas-tree" assembly. If the assembly is to be used in *flask* casting, it is surrounded by a flask and the flask filled with investment (much as in the lost wax process). If the assembly is to be used in shell casting, it is dipped into a ceramic slurry and stuccoed (refractory grain is sifted onto the coated pattern cluster). After this shell has dried, the dipping, stuccoing, and drying steps are repeated until necessary shell thickness has been achieved. The rest of the steps are essentially the same. The wax patterns are melted out of the mold and the molds are poured. After solidification and cooling, the mold material is broken away from the castings, the castings are removed from the sprue, gate stubs are ground off, and the castings are cleaned by shot blast (or some other method).

Flask casting was the predominant method for many years. More

recently, shell casting, which accommodates larger casting sizes more easily and reduces material costs, has come to be the more common method.

The materials used in producing patterns for investment castings are highly specialized and proprietary. Plastics are used to some extent, but wax is the most widely used pattern material. Venders supply waxes that conform to the needs of the investment caster. Some wax-injection presses use billets of wax that have been softened by preheating. Other presses use wax in liquid form. Waxes are a blend of natural and synthetic materials. They are available with different setting times, with slower-setting waxes being used for thicker patterns and faster-setting waxes for patterns with thin (under ⅛-inch) sections. Some of the properties waxes should possess are high strength and hardness at room temperature, minimum shrinkage, extended solidification range, little tendency to retain stress during solidification, dimensional stability in storage, minimum contaminants, and low cost. Commercial (and school) foundries are advised to secure waxes from a reputable supplier rather than trying to use material that "might work."

The materials used in mold making are also highly specialized. A number of suppliers provide binders and refractory materials. Some of the refractory materials are used with specific binders to produce slurries. Some binder systems are designed to gel the previously applied coating very rapidly. This eliminates the need for thorough drying between successive coats and permits the desired shell thickness to be achieved rapidly by dipping and stuccoing every 15 minutes. It is important that the refractory materials used for stuccoing be compatible with those used in the slurry. Using materials with significantly different thermal expansion rates may cause cracks in the mold. Here again, securing refractory materials that are specifically designed for the investment casting process being pursued and carefully following directions provided by the supplier are highly recommended.

Although investment castings tend to be small, castings of 1500 pounds (680 kilograms) have been produced. Larger investment castings will likely be made in the future as particular needs arise that are best met with this metalcasting process.

An almost unlimited range of commercial alloys have been used successfully in producing investment castings. However, the process is particularly advantageous when certain exotic alloys need to be formed. Some of these *must* be cast, because they cannot be forged or machined.

Advantages and Disadvantages

In comparison with green sand molding, the investment casting process has a number of advantages and disadvantages. Some of the advantages are:

- The process results in highly precise castings—so much so that investment castings can replace parts that previously were machined to shape.
- Investment castings have superior finish—smooth, virtually flawless surfaces.
- The castings produced have exceptionally sharp detail.
- Castings of superior density and integrity can be achieved by adjusting the temperature of molds and/or metal.
- The one-piece mold eliminates parting lines.
- Draft is not a factor; undercuts (reverse or negative draft angles) are permissable as long as the pattern can be ejected from the die.
- Investment castings require little or no machining.
- The process is environmentally cleaner.
- The process is easily adaptable to short or long runs.

Disadvantages of investment casting are

- Molds (and mold materials) can be used only once.
- The process (forming the mold) is relatively slow.
- In some cases, the process is more expensive than green sand molding and a number of other metalcasting processes.

Investment casting in industry is sufficiently specialized that facilities generally are designed to do just this type of metalcasting. Specialized facilities and/or equipment include temperature-controlled wax preparation areas, wax-injection presses, automatic mold conveyers, programmable robots (used for dipping and stuccoing the patterns), and autoclaves for dewaxing. Conventional heating/melting, cleaning, finishing, and inspection equipment can be modified or adapted to better meet needs that are unique to investment casting.

Investment casting can be accomplished without the degree of sophistication described above. Where necessary equipment is available to provide hands-on experiences in green sand molding, investment casting can be added as an *enrichment* activity. This can be accomplished with a very modest expenditure for certain special equipment, such as precise weighing and measuring devices, a mixer, and a vibrator. If time is limited, a short unit on the lost wax process may be adequate. However, if time permits, a unit on investment shell casting would be better.

Procedure for the Lost Wax Process

The following discussion assumes the use of Satin Cast 20 and a 1¾-inch diameter × 2¼-inch flask.

Producing the Pattern: Use sheet wax, wax wires of various gauges and cross-sectional shapes, and stick and/or block waxes of various hardnesses to fashion a pattern of the desired shape. Use commercially available tools (or improvised tools, such as discarded dental instruments, nails, small files, scissors, and knives) for carving and shaping the wax. Clean and polish the wax patterns with a piece of cotton and a mild soap solution. Rinse with room-temperature running water.

NOTE: If time permits, this is an activity that some people find most appealing, though hand-crafted wax patterns are not essential. Gift stores have a wide variety of small wax candles in many interesting shapes that can be used. Other pattern sources for organic materials that will burn out are bugs, seeds, pods, various shapes of macaroni—even bone, such as the wishbone from a small game bird. These are "ready-made" patterns. Experiment to see which of these organic patterns need to be sealed with acrylic spray so they will not change shape during investment.

Mounting the Pattern and Preparing the Flask:

1. Select a flask that will allow a minimum of ⅜ inch (9 millimeters) of investment between the pattern and the bottom and sides of the flask and ½ inch (13 millimeters) from the top of the flask and select a rubber sprue base that fits the flask.
2. Determine the amount of metal required. This can be done by weighing or water displacement.
   a. Weighing: Weigh the pattern on a precision balance. Multiply the weight by the specific gravity of the metal to be used to determine the weight of metal to melt. Wax has a specific gravity of approximately 1.0. A common copper-base red brass alloy, C83600 (85-5-5-5), has a specific gravity of 8.86. Multiply the weight of the pattern by the specific gravity of the metal. Add 40 percent more metal for sprue(s) and **button**.

Example

2.3	grams of wax pattern (specific gravity of 1.0)
× 8.86	specific gravity of brass
20.38	grams of brass needed to make casting
+ 8.15	grams of brass (40 percent additional for sprue(s) and button)
28.53	grams of brass to be melted

   b. Displacement: Fill a graduated cylinder to a specific line with water. Immerse wax pattern (attached to a thin wire) and note raised water level. Remove pattern and add metal to bring water to this same level. Add 40 percent more metal for sprue(s) and button.

3. Attach one or more short (not longer than ½ inch or 13 millimeters), thick (not less than ⅛ inch or 3 millimeters) sprue wax wires to the thickest portions of the pattern with a heated spatula.
4. Fill the center hole of the rubber sprue base with utility wax and let it harden.
5. Attach the sprue(s) to the utility wax with a heated spatula and sticky wax.

Investing the Pattern:

1. Paint the pattern with wetting agent (debubblizer) using a fine brush and allow to air dry. This will reduce the surface tension of the wax so the investment will lie against it smoothly.

NOTE: The work time after investment powder is introduced into water is quite critical. This operation should take as close to 9 minutes as possible. Less time will not allow proper wetting of all of the powder. More than 9 minutes may cause the mold to develop cracks as it hardens.

2. Determine water and powder requirements: 2 fluid ounces (56 milliliters) of room-temperature water and 5 ounces (142 milligrams) of Kerr Satin Cast 20 are recommended for a 1¾-inch diameter × 2¼-inch flask.
3. Mix about 10 percent of this to a creamy slurry, sifting the powder into the water.
4. Using a fine brush, paint the pattern with a thin layer of investment, covering all of its surfaces (Fig. 8-19).
5. Install the flask on the rubber sprue base.
6. Mix the remaining materials. Hold the mixing bowl against a vibrating device to cause air bubbles in the mix to rise to the surface (Fig. 8-20). One minute of vibration should be sufficient.
7. Pour investment into the flask by holding the flask at a slight angle and pouring down the inside edge of the flask until the investment has crept up and surrounded the pattern (Fig. 8-21). Vibrate the flask gently one last time, place it on a level surface, and top it off with investment.
8. Allow the flask to set undisturbed for *at least 1 hour,* after which the rubber sprue base can be removed with a gentle, twisting action. Larger flasks require longer set times.
9. Remove excess investment and brush away loose particles.

Figure 8-19
A fine brush is used to paint the pattern with a wetting agent. After this has air dried, the pattern is painted with investment. This helps to avoid air bubbles on the surface of the pattern.

NOTE: While the investment is setting up, preheating of the oven can be started.

Balancing the Centrifugal Casting Machine:

NOTE: This must be done *now* because casting must be done *as soon* as burnout is completed.

1. Place the invested flask in position at the proper end of casting arm with wax sprue end toward the center of the machine.
2. Place the crucible in the carriage and slide it up against the end of the flask.
3. Melt a small amount of flux in the crucible and glaze the bottom and side walls with a torch.
4. Place the metal to be melted in the crucible.

Figure 8-20
The investment, after being mixed in a rubber mixing bowl with a spatula, is held against a vibrator to cause air bubbles to be evacuated from the mix.

Figure 8-21
Pour the investment down the inside edge of the flask until it completely covers the pattern.

Figure 8-22
The swing arm of the centrifugal casting machine is held in a straight position with a paper clip and weights are adjusted to balance the weight of the invested flask and the metal to be melted.

5. Wedge a matchstick or paper clip to hold the swing arm in line with the straight arm (Fig. 8-22).
6. Loosen the center nut so the arm can tip up or down.
7. Adjust the weight(s) at the opposite end to balance the arm.
8. Tighten the center nut.
9. Remove the matchstick or paper clip so the swing arm returns to its right angle position.
10. Wind the machine by making three complete turns *clockwise,* locking it in place with the stop rod.

Burnout: Burnout eliminates wax and moisture and establishes the proper casting temperature for the mold. Burnout should be started soon after the recommended set time (1 hour with small flasks). If burnout cannot be done at this time, the invested flask should be wrapped in a wet cloth because molds that lose too much moisture are subject to cracking during burnout. Molds with questionable moisture content should be submerged in water until air bubbles cease, before proceeding with burnout.

NOTE: Do not start this operation unless you have time to complete it *and* pour the casting.

1. Place the flask, sprue side down, in an oven preheated to 300F (150C). Place the flask on a wire grid in a baking pan for *1* hour.

NOTE: All but traces of the pattern and sprue(s) will be lost in this step. Remaining burnout steps do not cause wax drippings or smoke.

2. Place the flask on its side in a furnace preheated to 700F (370C) for 1 hour; increase the temperature to 1350F (730C) for 2 hours. All carbon residue should have been eliminated by this step, leaving the mold cavity completely white.

NOTE: *Be careful not to exceed 1450F (785C) or the investment may be damaged.* Also, heated molds that are cooled below 500F (260C) and then reheated are subject to cracking.

3. Reduce furnace temperature during a 1-hour period to achieve the proper casting temperature for the mold:
   1000–1100F (540–595C) for light, intricate designs
   700–900F (370–480C) for heavier designs

Casting:

NOTE: Start to melt the metal several minutes *before* the burnout schedule is complete. Wear appropriate eye protection, such as oxyacetylene welding equipment with a 3- or 4-filter shade.

1. Use an oxyacetylene torch (or acetylene or propane) to melt the metal, sprinkling flux (proprietary or borax) on the metal as melting commences (Fig. 8-23). Be sure the flame is adjusted to neutral. Heat with the inner blue cone just *off* the metal. A carbon rod is useful for checking the fluidity of the metal. Once you have started heating the metal, keep it covered with the torch flame to curtail oxidation.
2. When the metal is molten, use tongs to remove the flask from the furnace and place it in position on the casting machine.
3. Slide the crucible carriage up snug against the open end of the flask.
4. When metal is sufficiently molten that it shines and rolls like mercury, grasp the weighted end of the casting arm and move it *clockwise* just far enough to allow the stop rod to drop. Keep the flame on metal during this operation.
5. Raise the torch and release the casting arm.
6. Allow the casting arm to spin until it stops.

Figure 8-23
The casting machine should be mounted in a tub for safe operation. An acetylene or oxyacetylene torch can be used for efficient melting.

NOTE: Some metals must be allowed to cool *in the mold* before being quenched. With yellow gold or sterling silver, wait about 4 minutes; with white gold, 15–20 minutes.

7. Many metals can be quenched after the red glow disappears from the sprue button. Use tongs to remove the flask from the casting machine and, holding it *horizontally,* quench in a pail of cold water, in and out, until all sizzling sounds cease. Then, drop it into the water.
8. Retrieve casting.
9. Remove the investment settlings and discard them *before* pouring quench water down the drain.

Cleaning, Degating, and Finishing:

1. Clean off investment with a toothbrush and water.
2. Saw off sprue(s) with a jeweler's saw (or snip off with cutting pliers).
3. File off sprue stub(s).

4. Using copper tongs or wooden chopsticks (*never* iron or aluminum tools), clean the casting by immersing it in a pickle solution, such as Sparex No. 2.

NOTE: If the pickle solution can be heated, this step can be accomplished in about a minute. A solution at room temperature requires more time, possibly 15 minutes or more.

5. When the casting is clean and bright, remove it from the pickle solution, rinse it thoroughly under running water, and dry it with an air gun.

NOTE: Some metals, such as brass, need to be coated with clear lacquer if the finish is to be preserved. This should be done immediately after final washing and drying; *do not* touch the metal with your bare hands.

Procedure for the Investment Shell Process

Producing the Pattern:

1. Pour molten wax into a pneumatic wax injector pot. Tighten the lid securely. Plug in, turn on, and adjust control to maintain 175F (79C). Connect the air hose and adjust air regulator to 5–10 pounds per square inch.
2. Examine the metal molds to see that they are clean. If necessary, clean with a soft cloth.

NOTE: Serviceable molds can be made of plastic or plaster.

3. Apply mold release: Spray the insides of metal and plastic molds with silicone. Soak plaster molds in water to prevent poured or injected liquid wax from sticking in the mold.
4. Fill molds: Hold the sprue opening in the mold firmly against the spring-loaded injector nozzle for 2–3 seconds, withdrawing it quickly so the nozzle will release rapidly and will not leak.
5. Allow the wax to solidify and cool so that it will not distort upon being removed from the mold. The time necessary for cooling will vary with the thickness of the wax pattern.
6. Open the mold and remove the pattern. Set the pattern aside carefully so it will not become damaged.

Clustering Patterns: Some investment shell castings are made individually, but when patterns are small they are clustered into what is sometimes called a Christmas-tree assembly. Such an assembly has a large number of patterns attached to a single sprue.

1. Form a pouring well. Ceramic pouring wells are commercially available, but expensive. A pouring well can be easily produced in the school foundry by filling a wax-coated paper cup with wax. When the wax is firm enough, the paper cup can be stripped off. (Fig. 8-24).

Figure 8-24
Top: Forming pouring wells by pouring wax into paper cups. *Bottom:* Stripping paper cup from wax pouring well.

2. Form the sprue, runners, and gates. Melted wax can be poured into fabricated metal trays of appropriate size and, when solidified, sawed into smaller pieces if necessary.

3. Attach a solid (or hollow) downsprue to the bottom of the pouring well. Attach runners to this at appropriate intervals. Attach gates to the patterns and runners. The assembly of such parts can be accomplished by dipping the areas to be joined in molten wax and pressing the parts together until cool, or a tool such as the temperature-controlled electric waxer, (see Fig. 8-25A) can be used to soften contact points before pressing parts together. Special assembly waxes, which function like hot glue, are used to build clusters without melting the pattern or gating components. When the assembly is complete, replace the screw eye in the center of the pouring well.

4. Clean the cluster. If silicone mold release was not used to make the patterns, wash the cluster with warm, soapy water, rinse in running water, and blow dry with an air gun. If silicone mold release *was* used, use a wetting solution to improve prime coat adhesion.

A B

Figure 8-25
A, An electric temperature controlled "waxer," useful in assembling clusters. *B,* An assembled cluster, ready for cleaning.

NOTE: The best test for determining whether a wax assembly is sufficiently clean is to dip it into the first slurry and see if the slurry wets, or coats, all areas of the pattern uniformly as it drains off. If it does, proceed. If it does not, rinse off the slurry in a pail of cold water and clean the problem area or the whole assembly as described above.

5. Hang the cluster on a storage/drying rack.

Mixing the Slurries: A number of proprietary investment materials are available. It is *important* to follow the specific instructions provided by the manufacturer of the materials.

There are two main types of slurries. *Fast-drying* slurries have a base of colloidal silica, water, and alcohol, or a base containing materials that gel chemically. *Normal-drying* slurries have a binder or base of colloidal silica and water. A refractory material (such as fused silica) in flour form is thoroughly mixed with the binder to form a thick slurry for *inner* coats (usually two). A coarser refractory powder is mixed in a similar manner to make a thinner slurry for *outer coats* (two to six or more). Such colloidal base slurries perform best if thoroughly dried (possibly for 4 or more hours) between coats.

1. Mix the inner coat slurry.

Binder	29 percent by weight
Refractory flour	Slightly less than 71 percent by weight
Wetting agent	0.017–0.034 percent by weight

Add about 90 percent of the flour to the binder. This should stir in readily. Add the remaining flour a little at a time as the previous addition is thoroughly absorbed. Then add the wetting agent a little at a time. It is best to mix the slurry at least 5 hours before it is to be used so that all dry materials can be fully wetted.

2. Mix the outer coat slurry.

Binder	38 percent by weight
Refractory powder	62 percent by weight

NOTE: Slurries should be covered to inhibit evaporation, and most will need intermittent stirring on a continuous basis (2 minutes of every 15 minutes).

NOTE: Properly mixed slurries are crucial to the process. Manufacturers of ingredients will provide specific proportions and mixing instructions together with ways of checking to see if mixed slurries are within specifications.

Slurries must be maintained between 75F (25C) and 85F (30C). Mixing propellers should not turn so fast that frictional forces increase slurry

temperature and cause excessive evaporation. Mixing should be done without producing excessive air bubbles in the slurry.

Given proper care, many slurries can be kept indefinitely.

Investing the Cluster:

1. Immerse pattern assemblies with a smooth continuous movement into the first slurry.
2. Withdraw the pattern assembly. Drain it and examine it carefully to see that all surfaces are covered and holes are open. If the slurry bridges across a hole, blow it open. If a certain area will not coat with slurry, wash off the slurry in a bucket of cold water and clean the area that did not coat.
3. Drain until dripping has stopped for the most part.

Stuccoing: While the slurry coating is still wet, apply stucco. The stucco is dry refractory material (sand) of appropriate grain fineness. It must be compatible with the refractory material in the slurry to avoid surface cracking of the mold. Preliminary or *inner* coats (usually two) are stuccoed with material of approximately 80 AFS grain fineness. *Outer* coats (from two to six) use material of approximately 40 AFS grain fineness. Stuccoing can be done in a variety of ways. The stuccoing material can be sifted over the slurry-coated pattern. It can be dropped onto the slurry-coated pattern with a "rainfall" barrel (Fig. 8-26). Alternatively,

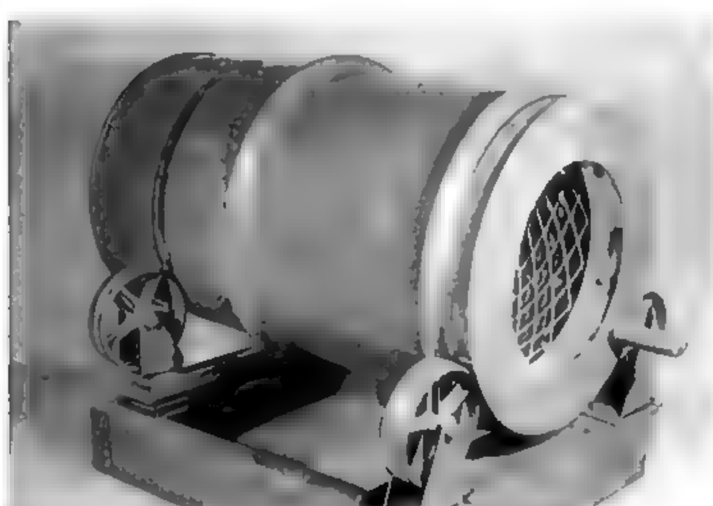


Figure 8-26
A rainfall barrel for stuccoing slurry-coated patterns developed by Dale Gray when he was a student in the Department of Industrial Technology at the University of Northern Iowa.

the slurry-coated pattern can be immersed into a fluidized bed of stuccoing material.

1. Apply refractory material to the slurry coating while it is still wet.
2. Hang up to dry.

Drying: The first and last coats must be completely dried. Other coats can be applied as quickly as the previous coat is firm enough that it does not slough off. Certain investment materials turn white as they dry and thus provide a good clue. In a school foundry, the first coat and the final coat should probably dry overnight. Intermediate coats might be applied during a class period depending on its length, although stronger shells result (with normal drying slurries) if each coat is completely dried (overnight).

Schedule for Shell Building Using Quick-Set Materials

	Day 1				Day 2						Day 3
	1	2	3	4	5	6	7	8	9	10	
PWS	dip										"Heat shock"
Slurry		BP	R	B	R	B	R	B	B	B	Dewax
Stucco		ZS	ZS	ZS	MG	MG	MG	MG	MG		Fire
Dry	20	150	30	ON	20	20	20	20	20	ON	Pour
											Shakeout

PWS = Buntrock pattern wetting solution
BP = Bluonic prime coat slurry, thicker than normal (18–20 seconds, No. 4 Zahn cup)
ZS = Zircon sand stucco
B = Bluonic slurry (8–12 seconds, No. 4 Zahn cup)
R = Redonic slurry (8–12 seconds, No. 4 Zahn cup)
MG = Mulgrain 22 s backup stucco

Drying time is minutes or ON (overnight)

Such a schedule, made possible by quick-set materials, fits school foundry instructional periods much better than do conventional colloidal silica materials that require extensive air drying between successive slurry/stucco coats.

Dewaxing the Shell: Waxes expand up to 12 percent prior to melting. Therefore, it is necessary to eliminate the wax in such a manner that the ceramic shell is not cracked by this expansion. One way to do this is by **shock heating.** Hold the pattern with the pouring well *down* in a furnace at 1500F (815C) for 20–60 seconds. This will cause the outer layer of wax to melt and run out, leaving room for the rest of the wax to expand, melt, and run out without damaging the shell.

1. Remove screw eye.

2. Using tongs or special holder, insert shell, pouring well *down,* into furnace preheated to 1500F (815C) for 20–60 seconds. (A crucible furnace can be used for this shock heating.)
3. Withdraw shell from furnace before the wax catches fire and shake melted wax into a waste can.
4. Stand assembly, pouring well *down,* on a shelf of an oven set at 250F (122C) to melt out remaining wax (Fig. 8-27). Place a collection can for the wax under the shelf. This wax, if kept clean, can be reused.

Firing the Shell:

1. Place the dewaxed shell on its side in a furnace preheated to 1400F (760C) for about 15 minutes, or until all traces of carbon have been burned off, leaving the inside of the shell completely white. It is important that the furnace be adjusted for an *oxidizing* atmosphere.
2. Shells can be removed from the furnace and cast immediately, or they can be allowed to cool, be stored, and be cast later. If this is done, recommended procedure is to reheat the shells before casting to ensure that any moisture absorbed by the shell is driven off.

Casting: Investment materials are often of sufficient strength to allow shells to be poured without additional support. However, it is recommended that shells to be poured in school foundries be placed in a metal bucket and surrounded with dry sand. Be careful to cover the pour cup before adding the sand (Fig. 8-28).

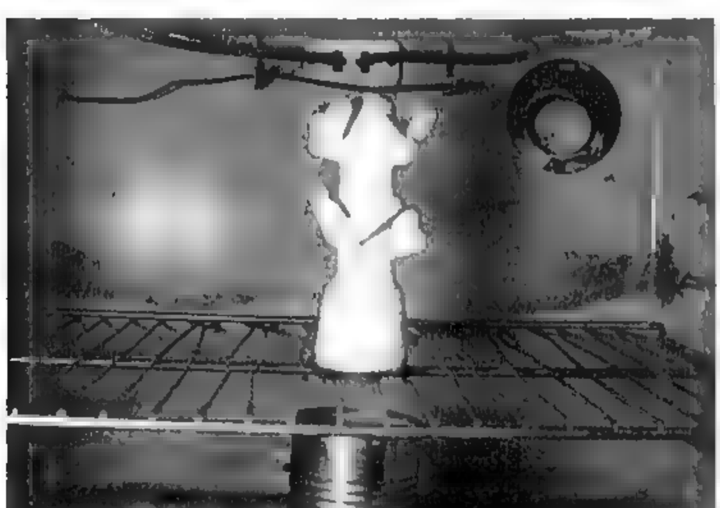


Figure 8-27
Oven heating of shell to drain (and collect) wax.

Figure 8-28
Pouring with the shell placed in a bucket, surrounded by dry sand.

Breakout: After cooling, the ceramic shell is broken away with a hammer or pneumatic chisel. Be careful that the casting is not damaged in the process. Remaining investment material can be removed by shot blasting, chemical leaching, or other appropriate means.

LOST FOAM PROCESS

The **lost foam process** is a method of making metal castings that uses expandable polystyrene patterns surrounded by unbonded sand. Metal poured into the mold vaporizes and replaces the foam pattern, producing a casting identical to the original pattern.

This process is unusual in a number of ways, including the ongoing controversy in the industry as to what the process should be called. At its first use, throughout its development, and more recently (as interest in the process has snowballed), the basic process has gone by a number of different names.

In 1958 a United States patent "Cavityless Casting Mold and Method for Making Same" was issued to Harold Schroyer. The process involved ramming green sand around patterns fabricated from expanded polystyrene material (like styrofoam). The procedure was basically identical to the green sand molding of a loose pattern except that the pattern was *left* in the mold instead of *removed;* thus, the procedure was called **cavityless casting.** The poured metal ran through the passageways of the mold and *replaced* the pattern by vaporizing the pattern material.

Six years later, in 1964, another United States patent was issued to T. R. Smith for making castings by using patterns *and* gating systems of

similar material in dry, free-flowing, unbonded sand. This was called the **full mold process.**

In 1981, after the expiration of both the above patents, considerable renewed interest in this process surfaced. In addition, a number of new names for the process, such as "lost pattern process," "evaporative foam process," "expanded polystyrene (EPS) molding," "EPC (evaporative pattern casting)," and "lost foam process," showed up in metalcasting magazines.

The present-day process is different in four major ways from what it was when T. R. Smith received his full mold patent in 1964.

1. Polystyrene bead manufacturers have developed *smaller* beads that produce better patterns.
2. The expandable polystyrene material is *molded* rather than fabricated from sheet stock. Patterns can be made rapidly and with much precision in much the same way that cores are blown or wax patterns are produced.
3. Specialized coatings have been developed that stiffen the pattern wall, control the rate of foam vaporization, and permit gases (formed as the polystyrene is vaporized) to pass through the coating.
4. Sophisticated vibration/compaction tables have been developed that move the dry, free-flowing unbonded sand into intimate contact with all surfaces of the pattern (regardless of its configuration) and densify it.

Useful new techniques, such as fluidizing the sand to assist in placing the pattern in the mold and putting the mold under a vacuum for pouring, have proved useful.

Another interesting difference between today's lost foam process and earlier processes is in application. Originally, the process was used to produce limited numbers of large-size castings from *fabricated* patterns. Now, efforts are focused on using the process for producing large numbers of small- and medium-size castings with *molded* patterns.

The lost foam process consists of placing individual or clustered expandable polystyrene patterns (sometimes called "softies") attached to gating systems of similar material in a flask surrounded by dry, free-flowing, unbonded sand. All parts of the polystyrene material (except for the top 1 inch of the sprue) are coated with a permeable refractory coating. The sand is vibrated and compacted so that it lies tightly against all surfaces of the coated pattern and gating system. The top 1–2 inches of the sprue remains *above* the top surface of the sand and is surrounded by an oversize pouring cup. Metal is poured into the cup, where it rests momentarily and then moves quickly downward through the gating system, vaporizing and replacing the polystyrene material as it goes. The

castings that are produced are identical to the original pattern. After solidification, the sand and casting can be poured out of the flask. To be reused, the sand needs only be screened and cooled below 140F (60C).

Those who are familiar with the green sand molding process can see more differences than similarities between the lost foam process and green sand molding. In green sand molding, much time, money, and attention must be devoted to conditioning sand so that it will make a good mold. The sand must then be rammed tightly so that it holds the shape of the pattern. Separate sand cores must be placed in the mold to produce holes and other internal shapes in the casting, and many pieces of expensive equipment are required to shake out the casting after it has solidified. None of the above is required in the lost foam process.

Molds consist of simple, one-piece flasks (like a huge bucket) and sand. The flasks usually have vents in the side walls or are double-walled and designed so that the top of the sand can be covered with plastic film and a vacuum can be applied to the flask and its contents. The sand needs to be sufficiently permeable to permit the escape of gases that are generated as the polystyrene is vaporized. A sand of 25–45 AFS grain fineness (rounded or angular in shape) is recommended. Surface finish is not affected by sand grain size because the molten metal never touches the sand; the metal lies against the coating on the pattern. One-screen sand (from which fines are eliminated) that can be cooled between use is all that is required.

Most commercial metals and alloys that are poured at temperatures of 1400F (760C) or higher have been cast successfully by the lost foam process, but some problems occur with certain metals or casting shapes.

Patterns (and some parts of the gating system) are molded of expandable polystyrene in much the same way that plastic foam coffee cups are made. Polystyrene is a straight-chain polymer with about 85.6 percent by weight carbon, 7.4 percent by weight hydrogen, and 7 percent by weight of an expanding agent such as pentane. Spheres of this material have a porous (sponge-like) center. They are capable of expanding 50 times. Small beads of this material that are 0.015 inch in diameter are called T-size beads. They have a bulk density of 40 pounds per cubic foot. In the presence of heat, the beads soften and expand. The beads are first pre-expanded to densities of 1.0–1.5 pounds. Then the pre-expanded beads are blown into molding machines where they expand even further and fuse together, forming patterns.

Adhesives used to fasten patterns to gating systems and multipart patterns together are specifically designed for use with expanded polystyrene. They must contain little or no ash, have a controlled set time, and have melting points that enable them to be used to join parts without damage or deterioration of the polystyrene. They must seal joints as well as adhere parts, so that coatings and sand grains do not work into joints and impede vaporization. In use, the adhesive is melted and maintained

at a specified temperature in a thermostatically controlled container. The end of one of the parts to be joined is dipped into the adhesive, pressed tightly against its mating part, and held under pressure for a few seconds, until the adhesive sets.

Refractory coatings are highly specialized proprietary materials. Zircon, silica, or graphite materials are combined with water or alcohol carriers. They should be matched to the type of metal that is to be poured. They must be maintained within a specified Baumé range (a measure of liquid density). Patterns and gating systems are best coated by brushing, overpouring, or spraying, since dipping is difficult. More than one coat is sometimes applied. Unlike most coating applications, *outer* surface smoothness of the coating is of no concern since the metal will contact the *inner* surface of the coating. Higher Baumé readings (thicker mixtures) are recommended for coarser sand and higher pouring temperatures. Coatings should be allowed to dry overnight. This time could be shortened with warm-air or low-temperature ovens set at 140F (60C) or less. Coatings stiffen the pattern walls, which helps to prevent sand collapse during pouring.

Gating is far simpler than that used in green sand molding. Research indicates that top, bottom, or side gating can be used successfully—foundries using the process normally use the type of gating that their experimentation has proved works best. The need for risers is greatly reduced. When risers are required, they are made of expandable polystyrene like the rest of the gating system. They are designed as blind risers, and are often spherical in shape.

Pouring rates must be monitored carefully. Pouring rates that are too fast might result in turbulent metal flow. This would vaporize the outside surface of the pattern first, trapping large amounts of gas, which produces voids in the center of the casting. Pouring rates that are too slow or are interrupted will almost always cause some parts of the sand mold to collapse. This prevents metal flow and results in catastrophic failure.

Pouring temperatures should be slightly higher than those used for green sand molding.

The sand must be properly compacted and there must be sufficient sand (or weight) above the pattern to enable the metal to replace the expanded polystyrene in the mold without distorting the sand mold. Failure to achieve both of the above conditions or having too thin a coating will result in shifting or bulging of the sand mold and in castings that are larger in certain areas than the pattern.

Advantages and Disadvantages

In comparison with green sand molding, the lost foam process has a number of advantages and disadvantages. Some of the advantages are

- Of the many green sand molding procedures, the following are not required in the lost form process:
  Conditioning sand—no binders, additives, mulling equipment
  Tucking, ramming, jolting, squeezing, striking off
  Sprue cutting
  Parting
  Pattern drawing
  Core making
  Core setting
  Touching up
  Slicking
  Blowing out the mold
  Mold closing
  Shakeout
- No cores are required.
- Draft is not required. In fact undercuts are not a problem as long as the mold is designed to allow ejection of pattern.
- There are no parting lines to grind off, which minimizes time in the cleaning room.
- Flasks are simpler and less expensive.
- There are no cope/drag registration problems.
- Shakeout becomes "pour out"—eliminating the need for capital-intensive, heavy, shakeout equipment.
- The sand is reusable after cooling.
- Yield is better.
- The process is cleaner and safer.
- Thin wall castings (as thin as 0.120 inch) are easier to produce.
- Complex, close-tolerance castings can be produced economically.
- The need for skilled labor is reduced.

Disadvantages of the lost foam process include:

- Flimsy or thin sections of a pattern may distort while being embedded or compacted in the sand.
- Pattern coating and drying are time-consuming.
- Patterns must be handled with great care, because even fingernail imprints in the pattern will be faithfully reproduced.

- Molded polystyrene patterns shrink approximately 0.100 inch per foot over a 30-day period and then become stable. To use patterns before shrinkage is complete requires precise planning if dimensions are critical.
- Pouring rate is more critical—interrupted pours invariably result in catastrophic failure.
- Pouring is more hazardous, since gasses rushing out of flask vents often burst into flame.

NOTE: The following disadvantages pertain to the acceptance rather than the technology of the process.

- The amount of technical information about the lost foam process is quite small and not nearly as available as that about some of the more conventional metalcasting processes.
- Because the foundry industry is capital-intensive, foundries are slow to replace conventional processes with newly developed ones.

The lost foam process has been used on a production basis by only a few foundries and for only certain types of castings. In 1980, General Motors Corporation's Central Foundry Division at Massena, New York, set up a high-volume production line to cast aluminum heads for 1982 Oldsmobile 4.3-liter, six-cylinder diesel engines by the lost foam process. The heads were produced from four molded patterns attached to a central sprue. This was the first use of this process for high-volume production. In early 1983, Ford Motor Company announced that it would use this process to produce 10,000 intake manifolds for some of the Tempo/Topaz engines produced that year.

Other large metalcasters are known to be working with the process on an experimental basis. There is a great deal of interest, as evidenced by the fact that workshops on the lost foam process are invariably filled to capacity. There seems to be little doubt that the lost foam process will play a significant part in the production of metal castings in the years ahead.

This process can be carried out successfully in school foundries. Several pattern producers have been willing to provide (at no cost) limited numbers of small-size molded polystyrene patterns so that students can have actual experience with the process. Manufacturers of refractory coatings and adhesives have been equally generous. Having these specialized materials enables the school foundry to carry out the lost foam process in much the same way that it is done on an experimental basis in industry. Even without the donated patterns and coatings, basic concepts of the process and useful hands-on experience can be gained through the full mold process (forerunner of the lost foam process).

Full mold casting involves fabricated, uncoated patterns, fastened together with adhesives such as rubber cement or white glue. Such activities are well within the capability of any educational metalcasting program and would serve well to enrich traditional instruction in green sand molding.

Procedure for Full Mold Process

Materials:

- Rubber cement or white glue
- Evaporative polystyrene in sheet form (blue insulation board in 1-inch thickness, available at all lumber yards, will work, as will material used in packing and shipping)
- Loose, unbonded sand
- Flask (bucket)
- Vibrator
- Metal

NOTE: Not all plastic foam materials are nontoxic polystyrene. Some are not safe to use. Test unknowns. Expandable polystyrene will ignite with a kitchen match, burn with an orange flame, produce pieces of carbon floating in the air, give off the odor of melted paraffin, and is not self-extinguishing.

1. Cut out the pattern with a hot wire machine (or any woodworking hand or power tool).
2. Design and cut the gating. Calculating the gating systems as described in Chapter 4 will work well, but gating can be much less complicated. Some research has shown that top, bottom, or side gating works equally well.
3. Attach the parts of the gating system to the pattern with rubber cement or white glue. (If white glue is used, the pattern should *not* be cast until moisture in the glue has dissipated. Waiting until the next day is best.)
4. Add about 3 inches of loose, free-flowing, unbonded sand (coarse grain) to the bottom of a one-piece flask (a 5-gallon metal bucket will be satisfactory for small work).
5. Place the pattern (with gating system attached) on the sand (Fig. 8-29).

Figure 8-29
Pattern and gating system placed on a bed of sand.

6. Add sand to gradually cover the pattern completely (including at least 3 inches of sand above the pattern); vibrate the flask as this is done (Fig. 8-30).

NOTE: The polystyrene sprue should stick up above the sand about 1 inch (26 millimeters).

Figure 8-30
Sand is added and vibrated until only the top 1 inch (26 millimeters) of the sprue extends above the sand.

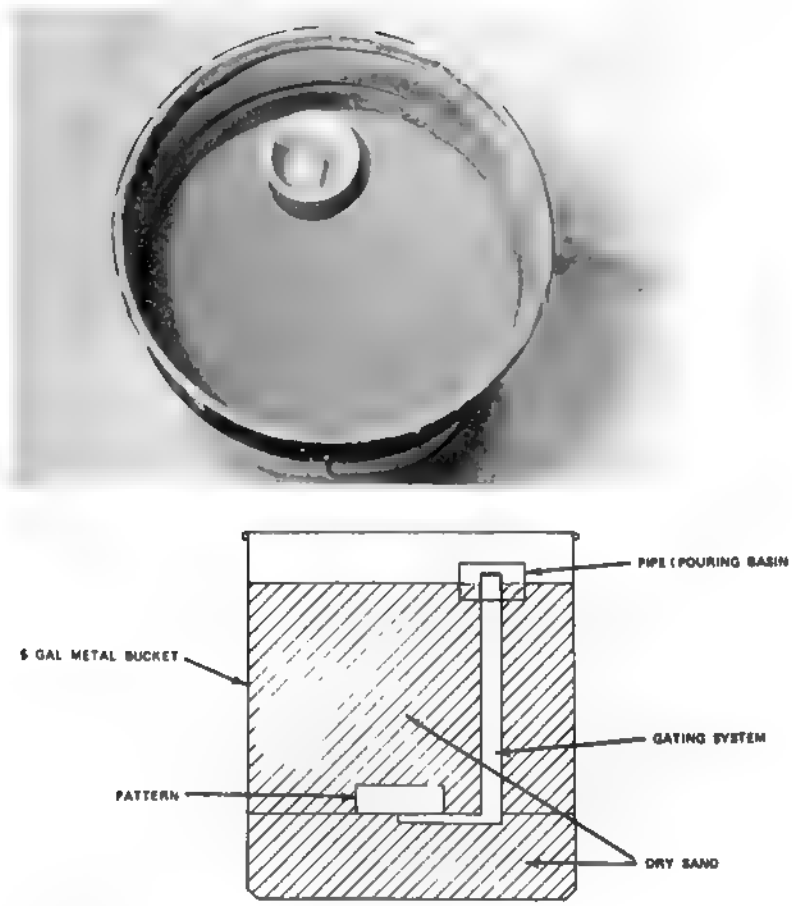


Figure 8-31
Top: The pour cup (piece of pipe coated on the inside and top edge with tool coating) is placed around the sprue and pushed down into the sand about 1 inch (26 millimeters). *Bottom:* Sketch of pattern and gating system in relation to the bucket (flask) and sand.

7. Place a pour cup (3 inches of 3-inch diameter pipe) around the sprue and work it down into the sand about 1 inch (Fig. 8-31).
8. Heat metal to about 50F (28C) higher than for a green sand mold for a similar pattern; for example, with a green sand mold: heat aluminum to 1380F (748C) and yellow brass to 2000F (1092C). For a full mold casting, heat aluminum to 1430F (776C) and yellow brass to 2050F (1120C).
9. Pour by filling the pour cup and keeping it full. The mold will take metal slowly at first and then very rapidly. Pourers *must be ready to pour quickly when the need occurs* and taper off toward the end of the pour.

10. Allow to cool until solidification is assured.
11. Shakeout: grasp the sprue with tongs and lift the casting from sand *or* turn the flask over and pour sand and casting onto a clean concrete floor.

NOTE: This must be done in such a way that the casting is not damaged and that there is no possibility of getting the sand used in this process mixed with the regular foundry sand. The concrete floor helps to cool the sand so that it needs only to be screened to be reused.

12. The casting produced should be identical to the polystyrene pattern and gating system. When cool, the steel pour cup will slide off of the aluminum that solidified in the pour cup.

Procedure for the Lost Foam Process

Materials:

- Special hot melt adhesive (Styrobond 52 or similar)
- Molded evaporative polystyrene patterns
- Evaporative polystyrene in sheet form
- Special refractory coating (Styrocast 250 or similar)
- Metal

1. Design and cut a gating system of evaporative polystyrene with a hot wire machine (or any woodworking hand or power tool).
2. Heat Styrobond 52 hot melt adhesive until it just liquifies.
3. Attach the parts of the gating system to each other and to the pattern. Touch the end of one part to the liquified adhesive and hold it tightly against its mating part for a few seconds, until the adhesive sets (Fig. 8-32).

NOTE: Production patterns often have gates molded with the pattern, which eliminates some assembly operations. On the other hand, many patterns are molded in more than one piece, which requires their being glued together.

4. Mix the coating material. Check its specific gravity with a Baumé gauge, and adjust to specifications if necessary.
5. Coat the pattern. The simplest way is to overpour it (Fig. 8-33). It is *important* that you leave the top 1 inch (26 millimeters) of the sprue *uncoated.*

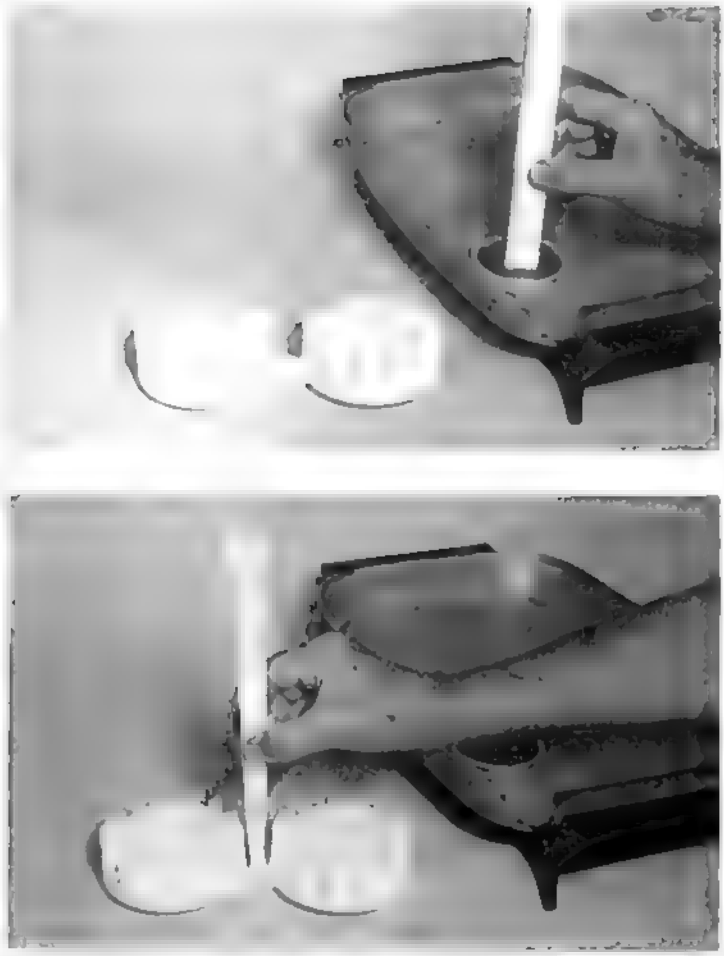


Figure 8-32
Top: Touching the end of the sprue to liquid hot melt adhesive. *Bottom:* Applying pressure to the joint until the adhesive sets.

NOTE: Additional coats may or may not be necessary. The coarser the sand, the hotter the metal poured, and the *higher* the **static head** of metal in the mold, the thicker the coating should be.

6. Allow the coating to dry thoroughly (overnight). Attach a large screw eye to the top of the sprue and hang the coated pattern on a drying rack.
7. Add about 3 inches of loose, free-flowing, unbonded sand (25–40 AFS grain fineness) to the bottom of a one-piece flask (a 5-gallon metal bucket works well).

Figure 8-33
Coating the pattern and gating system by overpouring. Do not worry if the exterior of the coating is not smooth—the metal will lie against the *inner*, smooth surface of the coating.

8. Place the pattern (with gating system attached) on the sand (Fig. 8-34). It is critical that the pattern be positioned in the flask so that added sand will contact all surfaces of the pattern and gating system and be firmly compacted.

9. Add sand to gradually cover the pattern completely (with at least 3 inches of sand above the pattern), vibrating the flask as this is done. The polystyrene sprue should stick up above the sand about 1 inch (Fig. 8-35).

Figure 8-34
The pattern (with gating system attached) is placed on the bed of sand and worked down into it so the bottom of the pattern and the sand are in direct contact with each other.

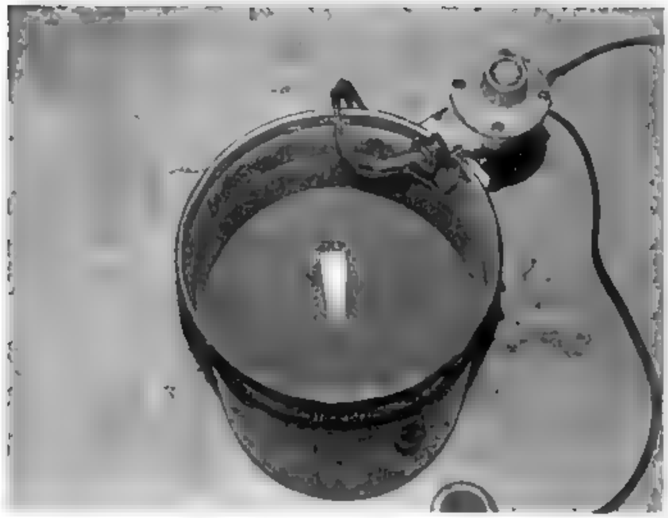


Figure 8-35
Sand is added (with continuous vibration) until only the top 1 inch (26 millimeters) is exposed above the sand. Substantially more sand needs to be added in this case. *Note:* Be sure that the top 1 inch (26 millimeters) of the sprue is *not* covered with refractory coating material.

NOTE: It is essential that sand be in firm contact with all surfaces of the pattern and gating system. Use an air or electric vibrator attached to the side of the flask and jolt the flask on the floor to ensure complete compaction.

10. Place a pour cup (3 inches of 3-inch diameter pipe) around the sprue and work it down into the sand about 1 inch. Weights are sometimes placed on the surface of the sand (Fig. 8-36).

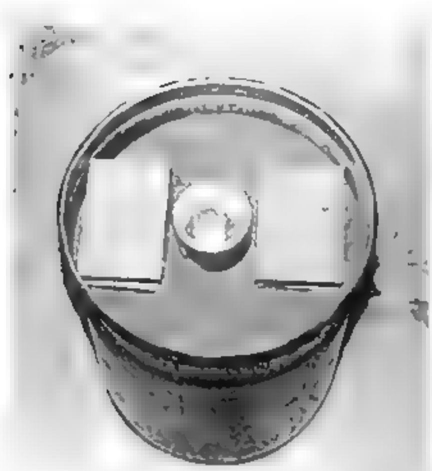


Figure 8-36
The pour cup (a piece of pipe with tool coating applied to the inside and the top edge) is placed around the sprue and pushed down into the sand about 1 inch (26 millimeters). Weights (stacks of 8–10 ¼-inch thick welding plates) have been placed on the sand above each pattern.

11. Heat metal to about 50F (28C) higher than for a green sand mold for a similar pattern. For example, with a green sand mold, heat aluminum to 1380F (748C) and yellow brass to 2000F (1092C). For a lost foam mold, heat aluminum to 1430F (776C) and yellow brass to 2050F (1120C).
12. Pour by filling the pour cup and keeping it full. The mold will take metal slowly at first and then very rapidly. Pourers *must be ready to pour quickly* when the need occurs and taper off toward the end of the pour. Some flaring will occur.
13. Allow to cool until solidification is assured.
14. Shakeout. Grasp the sprue with tongs and lift the casting from the sand *or* turn the flask over and pour sand and casting onto a clean concrete floor.

NOTE: This must be done in such a way that the casting is not damaged and that there is no possibility of getting the sand used in this process mixed with the regular foundry sand. The concrete floor helps to cool the sand so that it only needs to be screened to be reused.

15. When the casting is cool, the refractory coating that now coats the casting will flake off with pressure from an air gun or a fingernail.

V-PROCESS

Vacuum sealed molding of unbonded sand, more commonly called the **V-process,** was developed in 1971. It is a patented process that has been used to produce castings of all sizes and shapes in almost all metals with melting temperatures above 1200F (650C) except magnesium.

The basic principle of the V-process is that dry, free-flowing, unbonded sand in a closed container under vacuum conditions will behave like *solid* material as long as the vacuum is retained. The Japanese put this principle to practical use in developing this innovative metalcasting process. Of course, a number of technical problems related to the process had to be solved and a massive research effort was mounted, involving 42 engineers for 2 years. This resulted in the development of a very specialized plastic material and specialized equipment, such as hollow-walled (vacuum-chamber) flasks, that are critical to the process. The research effort also provided important data on sand type and distribution, amount of vibration required, amount and fluidity of metal in a V-process mold, and the volume of vacuum required.

The reaction of sand in a closed container when a vacuum is drawn is rather dramatic. The sand becomes quite hard and retains whatever shape it has when the vacuum is applied.

The steps to carrying out the V-process method of metalcasting are as follows:

1. Special, thin thermoplastic film is heated and vacuum-formed over a wood or metal pattern installed on a hollow carrier plate.
2. The drag is placed, pins down, over the pattern and filled with dry, free-flowing unbonded sand.
3. The drag is vibrated to compact the sand to maximum bulk density. The sand is then leveled and another sheet of plastic placed on top. Then a vacuum is drawn, causing the sand to become rigid.
4. The vacuum to the pattern carrier is turned off and the drag (with vacuum still applied) is stripped from the pattern and set on a bottom board in the pouring area.
5. The cope is made up in a similar manner with special attention to forming the down sprue.
6. The vacuum to the pattern carrier is turned off and the cope (with vacuum still applied) is stripped from the pattern and positioned on the drag, producing a plastic-lined mold ready for pouring. Cores, if needed, are set in the drag before the mold is closed.
7. The mold is poured. The vacuum is turned off a short time after pouring. After allowing adequate time for solidification, the bottom board is removed and the loose sand and the casting fall out.
8. The sand is cooled and screened to remove any small lumps before reuse.

The V-process is used, under a licensing agreement, in more than 100 foundries all over the world, a number of which are in the United States.

Specialized Material and Equipment

Those familiar with green sand molding sometimes have difficulty understanding how castings can be made in dry, free-flowing, unbonded sand. Of course, it cannot be done without some rather specialized materials and equipment.

Plastic Film: The plastic film is special in a number of ways. It is an ethylene-vinyl-acetate (EVA) thermoplastic material with a high deformation ratio and excellent shaping properties. The plastic develops no

toxic gas and is low in cost. It must not wrinkle or overlap, stick to the pattern material, or be elastic after forming. It is available in thicknesses of 2 mil (.002 inch or .05 millimeter) to 7 mil (.007 inch or .18 millimeter) and widths of 2 feet (610 millimeters) to 8 feet (2440 millimeters).

Heater and Plastic Film Carrier: The plastic film carrier is a frame to which the plastic film is attached for heating. In industry, the frame is often hollow and connected to the vacuum system. Many small openings on the underside of the frame enable the plastic to be held to the film carrier by vacuum. The plastic film heater is capable of producing a uniform temperature of about 200F (93C) over the entire surface of the film. The heater is movable. It is positioned above the plastic film away from the pattern. When the plastic is ready to be formed (having lost its opacity and begun to sag in the middle), it is moved *quickly* into position and draped over a pattern. Then the vacuum is applied. Film that is properly heated will form to the pattern within 5 seconds in a vacuum indicated by approximately 15 inches of mercury.

Patterns: Pattern requirements for V-process molding differ substantially from those in green sand molding. Pattern wear essentially is eliminated on V-process, since the sand is poured against the plastic-coated pattern (which is never touched by the sand), rather than being rammed, jolted, or squeezed against the surfaces of the pattern, as in green sand molding. This permits the use of much lower-cost wood patterns instead of the metal patterns needed in production green sand molding. Practice has shown that hard wood or epoxy patterns are less affected by temperature and humidity than the inexpensive soft wood patterns that were initially recommended.

Another important difference is draft. V-process molding can be done with patterns with zero draft or even slight negative draft. This is substantially different than the 2 degrees or more of draft necessary for green sand patterns and results in significantly less machining. In producing V-process patterns, loose wood patterns are mounted on high-grade plywood that has sufficient strength to remain flat in spite of vacuum forces or sand loading. Patterns and gating are attached to the plywood. Then small vent holes are drilled around the patterns and gating at intervals of ¼ inch (6 millimeters) (for detail and lettering) to 1 inch (26 millimeters) (for long, straight portions). Holes should be made in the center of letters such as O, B, and R. Holes also should be drilled in a 2-inch grid network over the part of the plywood not covered by pattern or gating system. The holes should be from .020–.028 inch (.50–.71 millimeters) in diameter and are often made with a solid piano wire G or E string. Holes spaced about 1 inch apart around the perimeter of the pattern plate (set in just far enough to clear the pattern carrier shoulder) will assist greatly in vacuuming and in holding the plastic film tight

to the pattern board during film carrier removal and flask installation. A final important difference is that fillets are *not* required in the production of V-process pattern plates.

Pattern Carrier: The pattern carrier is a five-sided box that allows the pattern plate to be flush mounted into place (on a shoulder) as the top, sixth side. A vacuum inlet is located in an out-of-the-way place. A grid of egg-crate design (with passageways for easy transfer of vacuum air) fits within the box to support flat-back pattern boards against vacuum forces and sand loads. In an industrial setting, the joint between the pattern board and the pattern carrier is sealed with a T-shaped rubber molding that also provides a highly desirable parting line sand to sand (actually, plastic to plastic) match since it supports the flask ⅛ inch (3 millimeters) above the pattern surface. In the school foundry, masking tape will provide the necessary seal.

Flask: Flask equipment for V-process molding is specialized in that flasks are double-walled and designed so that the entire perimeter of the flask serves as a vacuum chamber. About 50 percent of the area of the inner walls is removed and these "windows" are covered with 250-mesh, square weave, stainless steel cloth, sandwiched between pieces of perforated metal. These assemblies are fastened in place over the windows with pan-head, self-tapping sheet metal screws, and a high-temperature silicone sealant is used completely around the perimeter of each window. It is critical that a vacuum can be pulled on this flask without sand being pulled through any leak and into the system; if such sand enters the system and is not removed by filters, it will ruin the vacuum pump. A vacuum inlet is located where it does not interfere with flask assembly or clamping.

Sand: The sand used in the V-process is dry, unbonded, free-flowing sand. Silica, zircon, chromite, and olivine have all been used successfully. Maintaining the sand system is much less complicated than in green sand molding, since neither moisture nor additives of any kind are used, and no mixing is done.

The most important required characteristics for V-process sand (in order of importance) are, casting finish produced, maximum bulk density that can be achieved, and permeability. Size and shape of the sand grains affect all of the above, but sometimes in contradictory ways. For example, large, round sand grains provide greater permeability but lesser bulk density and poorer casting finish. Smaller, angular sand grains provide less permeability but improved bulk density and casting finish.

Since fewer gases are produced in the dry, unbonded V-process sand, high permeability is not of primary concern as it is in green sand molding.

Bulk density is the degree to which sand can be compacted by vi-

bration so that in a given space (like a flask), there is the highest amount of sand and the least amount of air possible. The greater the bulk density the less vacuum required for a mold to hold its shape and the greater the strength of the mold. Small, angular sand grains provide maximum bulk density but low permeability.

Of primary importance is good casting finish. Generally, fine sand (120 AFS grain fineness or finer) is recommended. The finer the grain size, the better the casting finish, but the lower the permeability. Using a thin layer of facing sand (180 AFS grain fineness or finer) backed up with less expensive, coarse, subangular sand (70 AFS grain fineness) is one way of achieving good casting finish, maximum bulk density, *and* adequate permeability. The disadvantage of using facing sand is that continued use results in the sand mixture gradually becoming finer. Another approach is to spray the plastic film with one *or more* coats of graphite mold wash prior to adding sand to the flask. Both of these techniques are used industrially. Mold wash enables the use of substantially coarser sand (around 50 AFS grain fineness).

After shakeout, the sand needs only to be screened and cooled before being reused. The screening removes small chunks of sand that have been joined together by the melting of the plastic. The temperature of the sand must be kept below 122F (50C) or the sand, when added to the flask, adversely affects the plastic film.

Vibrator: When dry, free-flowing, unbonded sand is added to a vacuum-chamber flask, it needs to be compacted to maximum bulk density. In industry this is done with a nondirectional vibrating table. School foundries will find that electric vibrators or air vibrolators work satisfactorily. Vibration causes sand grains to move close together and interlock with each other, eliminating much of the air that otherwise would be present between sand grains. Vibration should take place *during* flask filling and then be turned off. The excess sand is then struck off, the resulting surface is covered with plastic film, and vacuum is applied to the flask. This approach produces mold hardnesses of 90–95, rather than the hardnesses of 50–75 in molds that are not vibrated or are vibrated at the wrong time (such as after the vacuum is applied).

Vacuum System: The vacuum pump should be able to draw a "rough" vacuum equivalent to 15 inches of mercury (half an atmosphere) of sufficient volume in cubic feet per minute (CFM) to meet the needs of the various parts of the system: pattern carrier, flask, and film carrier (if vacuum type). Most industrial vacuum pumps are capable of drawing 20–22 inches of mercury prior to pouring.

Cores: Any type of dry sand core can be used with the V-process if its temperature is below 122F (50C). In addition, care must be taken when setting the cores that the plastic mold surface is not torn.

Pouring

In preparation for pouring, the cope and drag should be clamped together securely. Metal can be poured at a somewhat lower than normal temperature because of the improved fluidity provided by V-process molds. The pour must not be interrupted or the mold will collapse. The vacuum should be held for a certain length of time *after* the pour is completed. Times will vary with type of metal and section thickness. For example, 30 seconds might be recommended for 1-inch sections in aluminum castings while steel castings of the same section size might require 5 minutes. Most castings are allowed to cool in the mold for a time after the vacuum is turned off. If such "holding time" is used, the flask must be sitting on a bottom board or flat surface of some kind. With the mold supported in this manner, it will hold its shape even with the vacuum turned off.

Advantages and Disadvantages

In comparison with green sand molding, the V-process has a number of advantages and disadvantages.

Advantages pertaining to sand are

- Low cost
- Simple, easy to maintain sand system
- No moisture or additives
- No capital-intensive mixing and shakeout equipment
- Limited waste sand

Advantages pertaining to tooling are

- *Much* less expensive patterns of wood or plastic
- Dramatically reduced machining costs resulting from zero-degree draft
- Much less pattern maintenance

Advantages pertaining to the molding process are

- More dimensionally precise castings due to more rigid mold (no wall movement)
- Casting cleaning greatly reduced
- Better as cast surface
- Improved fluidity of plastic-lined gating systems results in thinner sections being poured successfully
- Slower cooling of the mold results in increased riser effectiveness and thin iron sections that are free of carbides

Advantages pertaining to the working environment are

- Cleaner, less dusty work area
- Reduced noise level
- Less smoke and fumes

Disadvantages of the V-process include

- Presently, the V-process does not lend itself to high production. It has found a niche in jobbing shops where molds in 30 × 30–inch or larger flasks are produced at the rate of 5–10 per hour.
- With certain casting shapes with narrow, deep pockets, the plastic film cannot be properly formed against the pattern consistently.

The V-process is such a dramatic departure from other metalcasting processes that it deserves to be a part of any effort to enrich traditional metalcasting instruction. Certainly, many of the important concepts involved in the process can be learned in a classroom setting. Demonstrating how a vacuum applied to sand in a rubber glove causes the sand to be rigidified is easily done, and is guaranteed to capture the interest and excite the imagination of students. Of course, if equipment can be developed so that students can see an actual demonstration or have hands-on experience with the process, this is even better. Although the process is patented (commercial foundries can use it only under a licensing arrangement), school foundries that are not involved in selling castings are at liberty to use the process for instructional or experimental purposes. The licenser of the process in North America, the Herman-Sinto V-process Company of Zelienople, Pennsylvania, cannot provide certain technical information without threatening the license. However, the company has provided assistance in the form of information and special materials to educational institutions trying to provide instruction about the process. Developing equipment that students can use is more challenging than tooling up for the other innovative metalcasting processes covered in this chapter, but it can be done (Fig. 8-37). The following procedure uses such equipment.

Procedure for the V-Process

Setup and Preparation:

1. Check all filters (three primary hose filters and two secondary pump filters). If broken or dirty, they should be replaced.
2. Check automatic oiler above the vacuum pump and fill to proper level, if necessary, with No. 10 oil.

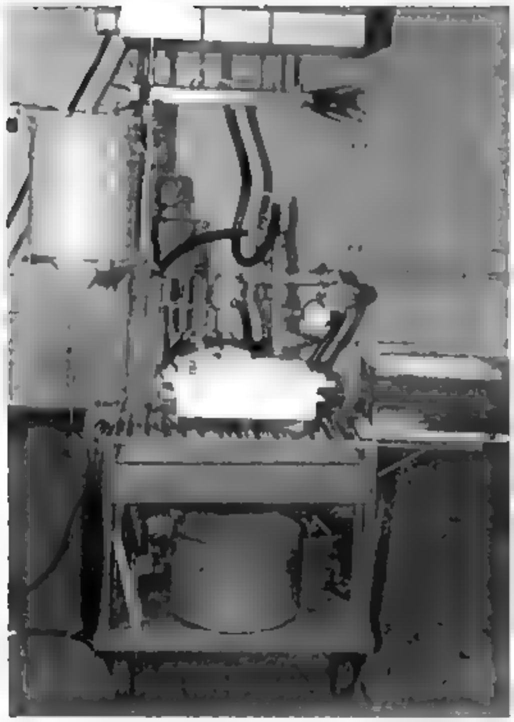


Figure 8-37
V-process equipment mounted on a cart. This equipment is the result of work by a number of students at the Department of Industrial Technology of the University of Northern Iowa.

3. Move the V-process equipment cart to an open area of the laboratory. The floor should be clean. A utility post with two 220-volt outlets (one for the vacuum pump and one for the heater) and a source of air pressure for the vibrator should also be available. In addition, the location should be reasonably close to the foundry area.
4. Plug in the heater and connect the vibrator hose to the air line.
5. Fill the sand hopper from the lower container, if necessary.
6. Make sure that all of the vacuum lines are connected and valves are closed. *Don't overlook the bleeder valve* on the pattern carrier.
7. Cut four to six pieces of plastic film using a clean bench, cutting board, and template. A razor blade cutter works well.

Preparing and Molding the Drag:

1. Swing the pattern carrier into place over the workbench.
2. Install the drag pattern board (the one with the pattern, sprue base, and runners) in the pattern carrier (Fig. 8-38).

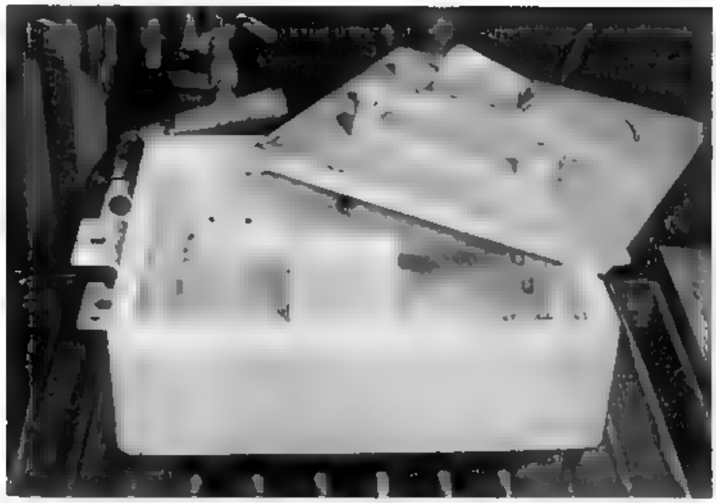


Figure 8-38
The drag pattern board is placed on the shoulder of the pattern carrier with the support block approximately centered. Note the saw kerfs in the top of the block, which allow vacuum to work.

NOTE: Make sure that the wooden support block is under the pattern board, approximately in the middle.

3. Make sure that the red marks of the pattern carrier and the pattern board align, then seal them together with masking tape, leaving an extra "lip" on the tape for easy removal (Fig. 8-39).

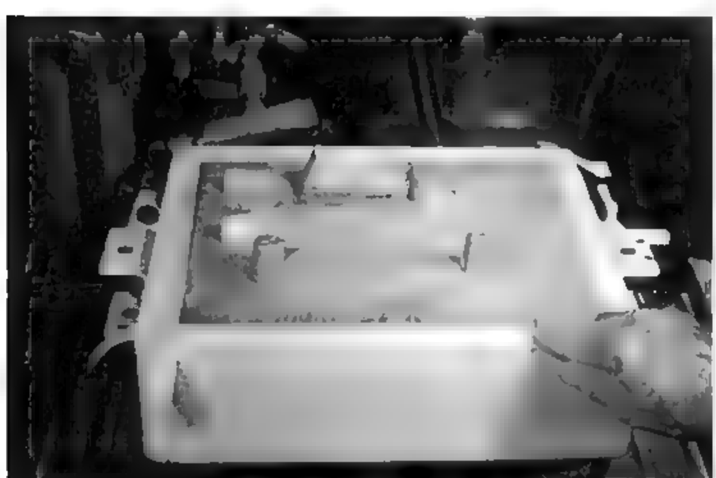


Figure 8-39
The joints between the pattern board and carrier are sealed with masking tape. Leaving a "lip" on each piece of tape makes its subsequent removal easier.

4. Turn on the overhead heater and allow it to warm. Position it to the *left* side of the pattern carrier.
5. Place the L-shaped pins in the pattern carrier for easy and proper alignment of the plastic film carrier (Fig. 8-40).

NOTE: The *red* pin goes into the bracket on the left with the painted surface up, and the other pin goes into the bracket on the right.

6. Start the vacuum pump and wait until the vacuum gauge shows at least 20 inches of mercury.
7. Attach a precut sheet of plastic to the film carrier with a binder clip at each corner.

NOTE: The plastic should be wrinkle-free with an equal amount of excess material on all four sides of the film carrier.

8. Open the valve to the plastic film carrier (*top* valve).
9. Allow the film to heat until it loses its opacity and sags 2–3 inches.
10. Carefully lift the film carrier from its hanger and lower it over the pins on the pattern carrier.
11. Drape the plastic film over the pattern, pushing the film carrier down as far as it will go.

Figure 8-40
L-shaped pins to guide the film carrier into position are positioned in the brackets on the pattern carrier.

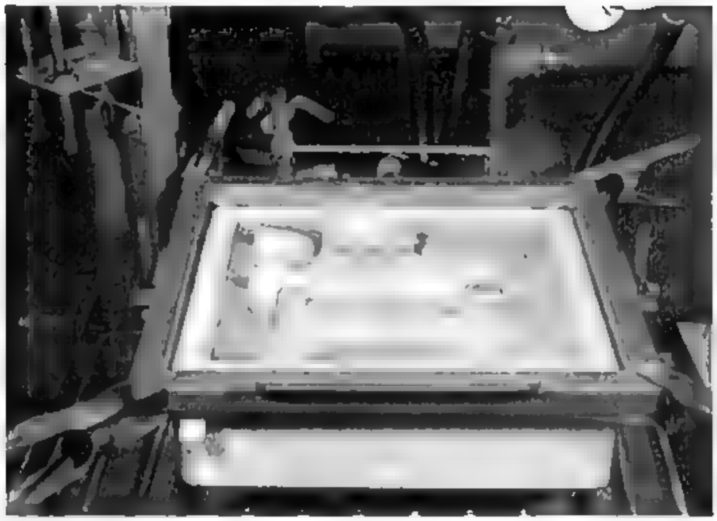


Figure 8-41
When the film carrier is in position, the plastic drapes over the pattern and contacts the pattern board around its edges. When the valve to the pattern carrier is opened, the film is formed tightly against the pattern.

12. *Immediately,* open the valve to the pattern carrier (*center, left* valve) to vacuum form the plastic. If someone is available, have that person help you time this correctly (Fig. 8-41).
13. Close the *top* valve (to the film carrier).
14. Return the film carrier to its hanger under the heater.
15. Swing the heater out of the way.
16. Make sure that the plastic is smooth and tight around the pattern and covers the pattern board completely.
17. Remove the L-shaped pins from the pattern carrier and return them to their holder.
18. Position the drag (vacuum outlet *away* from you and pins *down*) on top of the pattern carrier.
19. Pull the plastic tight and smooth from the outside of the drag. The drag will help form a tight seal. Fold excess plastic and tape to sides of flask.
20. Swing the sand hopper over the flask and fill with sand as the pattern carrier is vibrated (Fig. 8-42).
21. Turn off the vibrator.
22. Level and strike off the excess sand.

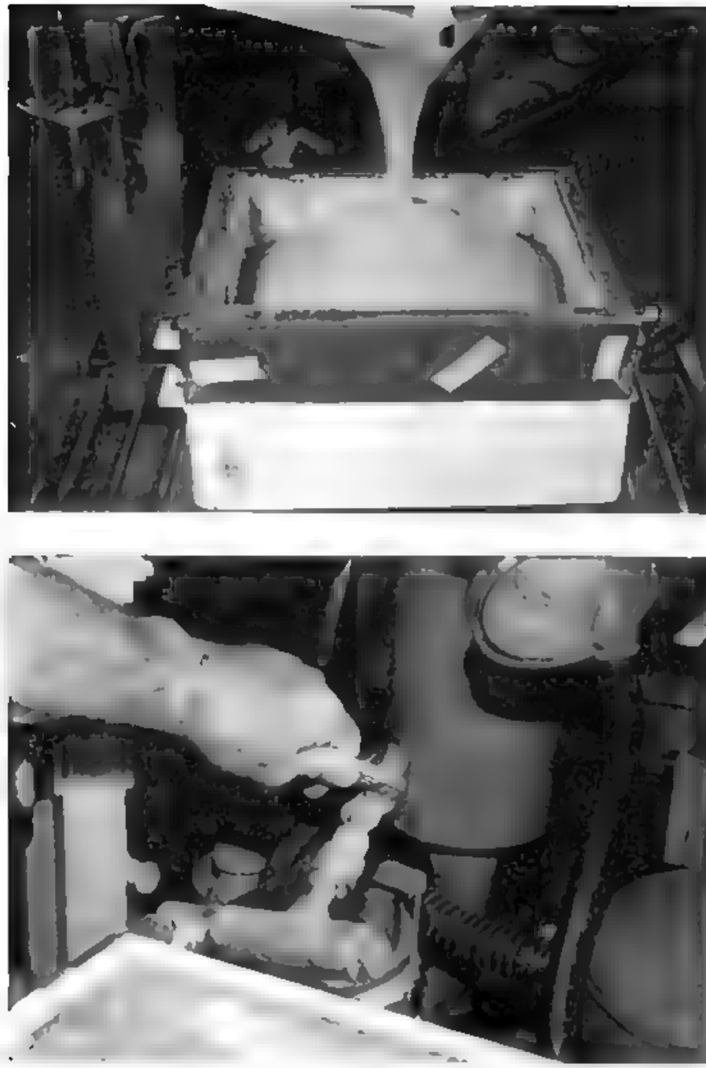


Figure 8-42
Top: Sand hopper fills flask quickly. *Bottom:* Valve to vibrator on pattern carrier is turned on *during* the flask filling operation.

23. Clean the sand off of the top edges of the drag so the plastic will form a good seal.
24. Lay a sheet of plastic film over the drag and apply vacuum (*bottom right* valve).
25. *Close* the valve to the pattern carrier (*center, left*) and open the *bleeder* valve on the right end of the pattern carrier (Fig. 8-43).
26. Fold excess plastic and tape to the sides of the flask in such a way that the plastic does not get in the way around the pins.

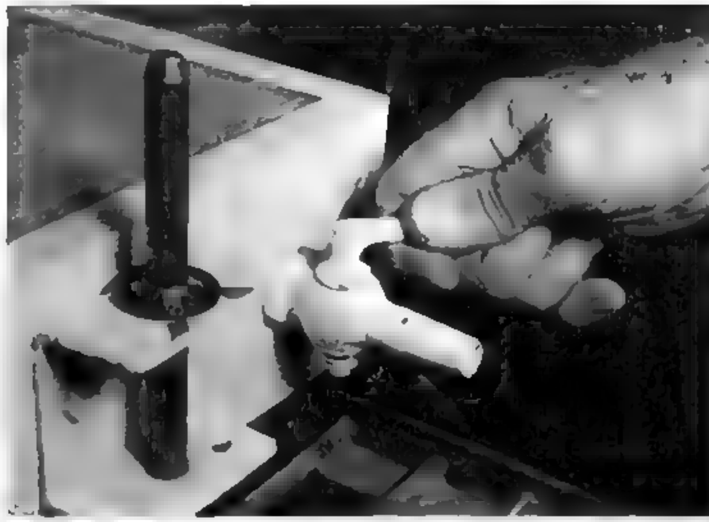


Figure 8-43
After the vacuum to the pattern carrier has been turned *off*, the vacuum must be "bled off" the pattern carrier before the drag can be removed.

27. Place the bottom board on the support to the right side of the work bench.
28. Lift the drag straight up and off the pattern carrier.
29. Turn the drag over and place it on the bottom board with the pins *up* and the vacuum outlet away from you (Fig. 8-44).
30. Close *bleeder* on right end of pattern carrier.

Figure 8-44
Drag resting on bottom board. Notice the plastic-lined cavity.

31. Check to see that a good mold surface has been achieved.
32. The vacuum hose to the drag should be the only one on at this time and vacuum gauge should show 17–20 inches of mercury.

Preparing and Molding the Cope:

1. Remove the tape and the drag pattern from the pattern carrier and set aside carefully.
2. Install the cope pattern (the one with the sprue, gates, and risers) into the pattern carrier.
3. Make sure that the red marks line up.
4. Seal all sides of the pattern to the pattern carrier with masking tape, leaving an extra lip for easy removal.
5. Insert the L-shaped pins as before, *red* pin to the left.
6. Attach plastic film to the carrier with a binder clip at each corner as before.
7. Open the valve to the plastic film carrier, *top* valve.
8. Swing the heater unit over the pattern.
9. Allow the film to heat until it loses its opacity and sags 2–3 inches.
10. Carefully lift the film carrier from its hanger and lower it over the pins on the pattern carrier.
11. Drape the plastic film over the pattern, pushing the film carrier *down* as far as it will go.
12. *Immediately,* open the valve to the pattern carrier, (*center, left* valve) to vacuum-form the plastic.
13. Close the *top* valve (to the film carrier).
14. Return the film carrier to its hanger under the heater.
15. Turn off the heater and swing it out of the way.
16. The plastic film should cover the entire pattern board and be smooth and flat.

NOTE: Do not worry if there is a thin plastic web, or **fin,** between the risers or sprue. This can be removed (and sealed with a hot soldering copper) or left in place.

17. Remove the L-shaped pins (return them to their holder) and insert the straight pins. The *left* pin should be *all red* with *one blue mark,* and the right pin should have *two blue marks* on the *top* side. Line these marks up with the ones on the pattern carrier (Fig. 8-45).

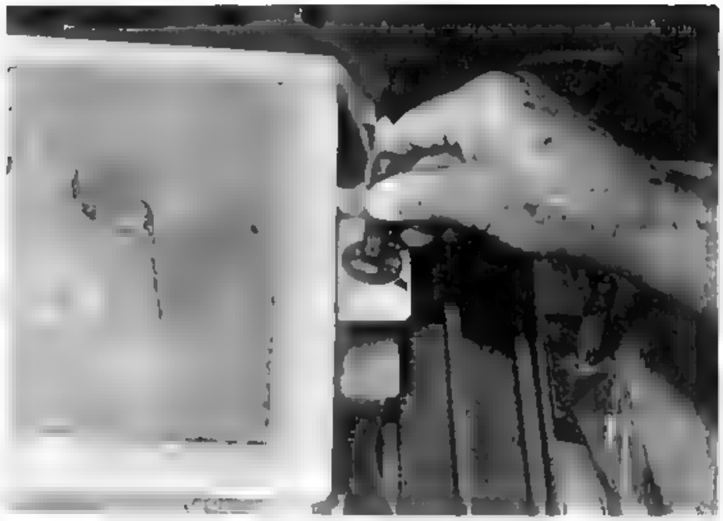


Figure 8-45
Before the cope can be placed on the pattern carrier, the L-shaped film carrier guide pins must be replaced with the straight pins to guide the cope into its proper position on the pattern carrier.

NOTE: These marks are aligned to ensure that the cope can be installed easily over the pattern carrier and removed with little resistance.

18. Place the cope (vacuum outlet *away* from you) over the pins of the pattern carrier.
19. Pull the plastic tight from the outside of the cope. The cope will help seal the film to the pattern. Fold excess plastic and tape to side of flask.
20. Swing the sand hopper over the flask and fill with sand as the pattern carrier is vibrated.
21. Turn off the vibrator.
22. Level and strike off the excess sand.
23. Clean the sand from around the edges of the cope so that the plastic will form a good seal.
24. Locate the sprue and clean off the sand above it (Fig. 8-46).
25. Lay a sheet of plastic film over the cope and apply vacuum (*bottom left* valve).
26. Close the valve to the pattern carrier (*center left*) and open the bleeder valve on the right end of the pattern carrier.

Figure 8-46
The top of the sprue is just below the surface of the sand. It must be found and cleared of sand.

27. Lift the cope straight up and off the pattern carrier.
28. Check to ensure that a good mold surface has been achieved. Then place the cope carefully on the drag so that both vacuum outlets are away from you.
29. The vacuum hoses to the cope and drag should be the only ones on, and the vacuum gauge should show at least 15 inches of mercury.
30. Place the special metal plate support for the pouring basin over the cope, with the hole in the plate positioned above the sprue hole in the mold.
31. Place the pouring basin in the opening of the plate so that the hole in the pouring basin is positioned above the sprue hole (Fig. 8-47).
32. Clamp the flask together between the bottom board and the top metal plate; clamp on opposite corners (Fig. 8-48).
33. Return straight guide pins from pattern carrier to their holder and swing pattern carrier out of the way.

Pouring the Mold:

1. Melt the metal as usual.
2. Adjust the position of the flask, if necessary, so that the pourers can get the lip of the crucible close to the pouring basin without interference of any kind.

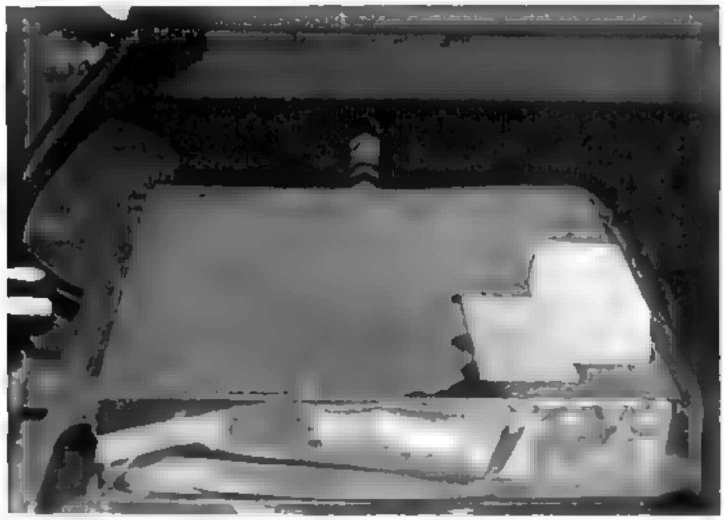


Figure 8-47
A pouring basin is placed in the opening in the special metal plate so that the hole in the pouring basin aligns with the sprue hole.

Figure 8-48
Clamp the flask on *opposite* corners.

3. Make the pour. *Do not* interrupt the pour or the plastic film will vaporize too quickly and the mold will collapse (Fig. 8-49).
4. After the pour is completed, count off 30 seconds for aluminum or 50 seconds for brass, and turn off the vacuum pump.
5. Wait about 10 minutes for aluminum or 20 minutes for brass for the metal to solidify, then proceed with shakeout.

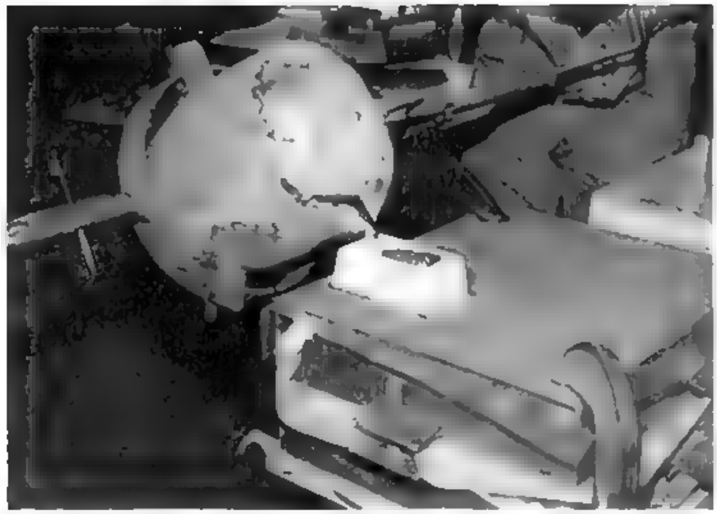


Figure 8-49
Pour the mold without permitting the stream of metal to be interrupted.

Shakeout and Cleanup:

1. Unplug the heater cord and wind it on the special holder provided.
2. Unplug the vacuum cord and wind it on the special holder provided.
3. Remove the C-clamps, top metal plate, and pouring basin.
4. Sweep the floor area *around* and *under* the cart.
5. Move the entire flask and bottom board to the main area of the workbench.
6. Lift the flask and the casting will be exposed (Fig. 8-50).
7. Use tongs to remove the casting and set it aside to cool.
8. Detach the vibrator from the pattern carrier, connect it to the rear of the screen, and turn it on.
9. Dump sand through vibrating screen back into the container. When finished, turn off vibrator.
10. Empty the container of sand onto clean concrete floor.
11. Allow the sand to cool; it must be cooler than 125F (52C) before it can be reused.
12. Remove the sand hopper from its holder and place on special *orange* cylindrical fixture on the floor.
13. Transfer the cooled sand from the floor to the sand hopper and replace the sand hopper in its holder.

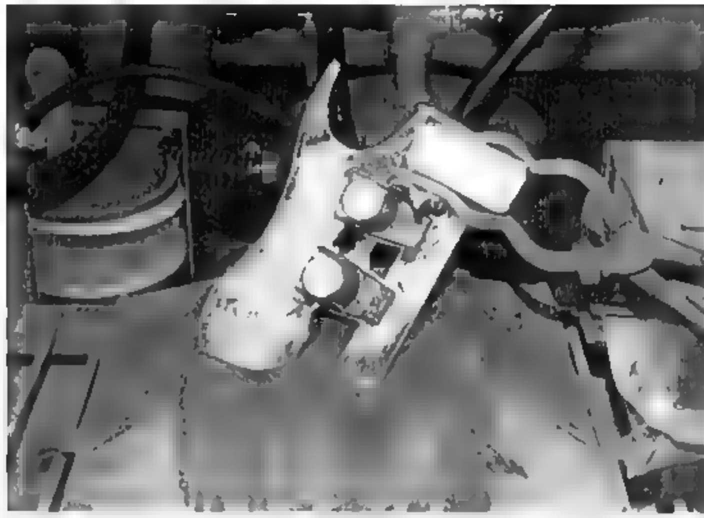


Figure 8-50
The casting can be picked out of the loose, free-flowing, unbounded sand easily.

14. Return the vibrator to the pattern carrier and *disconnect* the air hose from the utility post.
15. Remove the screen and discard the material remaining on it.
16. Clean up the V-process machine and put all equipment back in place.
17. Replace the screen in its special holder.
18. Return the V-process cart to its usual position.
19. Sweep the floor.
20. Clean the casting in the abrasive blast cabinet.

H-PROCESS

One of the most recently developed metalcasting processes is the Horizontal controlled flow casting method, better known as the **H-process.** The process was developed in the United Kingdom in 1975. It is patented, and commercial foundries must purchase a license to use the process. The licensing agent, in turn, supplies specific technical information to the licensee.

The H-process resulted from Fred H. Hoult's desire to increase **yield.** Some castings made in green sand molds have gating systems that weigh as much as the casting. If only 50 pounds of castings result from 100 pounds of metal poured into a mold, the yield is only 50 percent. The other 50 pounds of metal is not wasted, in that the metal can be remelted

and used, but the remelting requires expensive energy. Whenever yield can be increased, the amount of remelt materials (gates, runners, risers, and so on) is decreased, and costs are reduced. Other advantages in efficiency provided by the H-process are that a whole "string" of molds (up to 50) can be filled in a *single pour,* and castings often can be broken (rather than cut) from the gating system.

In Chapter 3, it was pointed out that some core sand mixtures and processes are easily adapted to moldmaking. A good example of this is the H-process, which utilizes a number of coremaking processes to make rigid, double-sided molds. Some of the coremaking processes most commonly used for the H-process are shell, sodium silicate/CO_2, and coldbox.

The molds are stacked vertically as they are made to minimize warpage and to ensure alignment, which is achieved through built-in locators. When mold assembly is complete, the string is clamped together and lowered to a horizontal position so that the molds are vertically oriented. Provision is made for pouring into the first mold, and the final mold is closed off, with a plain slab of core sand. When poured, each mold fills before the metal in that cavity rises to a point where it starts to fill the next cavity. Each cavity is filled, in turn, in a controlled manner.

The H-process requires few pieces of specialized equipment. Coreboxes that produce double-sided, rigid molds need to be fabricated. On each side of the mold is a half impression of the required casting and part or all of the gate and **runnersphere,** which makes up the specialized gating system. The runnersphere is the heart of this process. When properly designed, the runnersphere in each mold will be of the right size and will contain a **well, weir,** and a **slag trap.** The metal flows into the well and then into the mold cavity. When the cavity is full, the well fills to the point at which it flows over a weir (or dam) and into the next well, filling that cavity, and so on. The portion of the runnersphere above the weir traps floating slag.

Different metals require runnerspheres of different dimensions. The runnersphere not only controls the flow of metal to each cavity in turn, but also provides feed metal to the casting to compensate for shrinkage. The heat from the large volume of metal in the runnersphere and the small sand-to-metal ratio creates a hot spot that keeps each gate molten and capable of feeding metal from the runnersphere to the cavity.

The H-process has been shown to be suitable for both light and heavy nonferrous alloys and for all ferrous alloys.

Advantages and Disadvantages

In comparison with green sand molding, the H-process has a number of advantages and disadvantages. Some of the advantages are

- The H-process results in higher yield.
- It conserves energy—fewer returns to remelt.

- The sand-to-metal ratio is much smaller (1:1 to 2:1).
- The process aids in controlled pouring—only one mold (in a string of molds) is lost if the ladle runs out of metal during a pour.
- Molds produced by several of the coremaking processes can be stored and cast according to best productivity schedule.
- An entire string of molds (up to 50) can be filled in a single pour.
- Uniform cooling of mold string results in a more uniform hardness.
- Castings are more dimensionally precise with little finning.
- Better as-cast surface is achieved from a rigid mold.
- Fewer slag defects occur, since slag is trapped in top portion of runnersphere.
- Smaller gates permit gates to be broken off; castings therefore require less grinding.
- The capital cost is low.
- The process has a high casting output per square foot of floor space.

Disadvantages of the H-process are

- Casting size is limited to the size of the core blower, shell core machine, or whatever equipment is used to produce the molds.
- Sand can be used only once unless it is reclaimed.

At the Rotherham Foundry of W. H. Booth and Company, Limited (United Kingdom), where the process was developed, the H-process has been used primarily for casting all grades of ductile iron. A number of foundries throughout the world have been licensed to use this process.

The H-process can enrich metalcasting instruction that concentrates largely on green sand molding. Although the process is patented and used by commercial foundries through a licensing agreement, school foundries, where castings are not sold, are at liberty to experiment with the process. The licensor of the process in the United States, Miller and Company in Chicago, cannot provide specific technical information without threatening the license. However, enough information has been provided to enable enthusiastic students to fabricate coreboxes with runnerspheres of their own design and see how well they work. Interesting hands-on experience can also be gained by carrying out the process with coreboxes others have built. The following procedure utilizes the sodium-silicate/CO_2 process and a "teacher-made" corebox to produce the molds.

Procedure

1. Clean the corebox with an air gun and/or a cloth.
2. Dust the corebox with parting compound (Fig. 8-51).
3. Fill and pack sand in corebox (use coreblower, if available).
4. Rap or vibrate the corebox to loosen the sand in the box.
5. Gas with CO_2 at 5 pounds per square inch for 10 seconds.
6. Strip the mold from the corebox (Fig. 8-52).
7. Stack molds vertically in special clamping fixture—use hacksaw blade to create a sprue hole in the first mold (Fig. 8-53).
8. When enough molds have been produced, seal off the runnersphere of the *final* mold in the string with core sand.
9. Place a metal plate on the top mold and clamp the string of molds just snugly enough to permit tipping the fixture to a horizontal position (Fig. 8-54). *Do not* clamp so tightly that you crack the molds—the hot metal will cause the molds to expand somewhat and to tighten the joints where the individual molds come together.
10. Move the mold string to the pouring stand.
11. When the metal is at the proper temperature, pour continuously (with lip of crucible as close to the sprue as possible) until the mold string will take no more metal (Fig. 8-55).

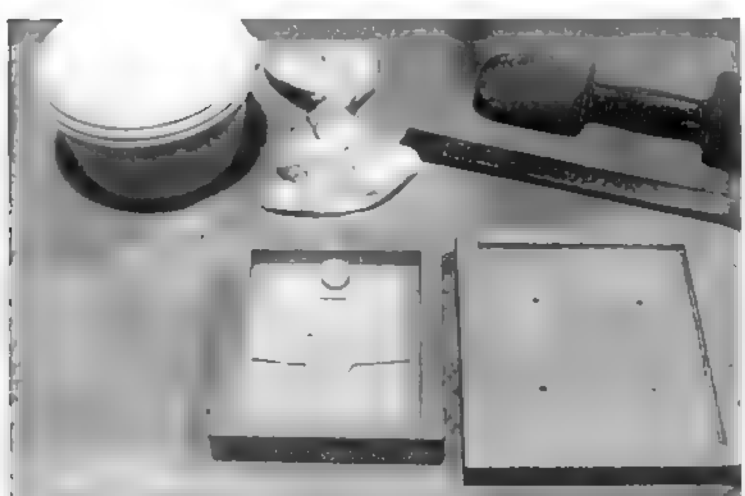


Figure 8-51
The special H-Process corebox has been dusted lightly with parting compound.

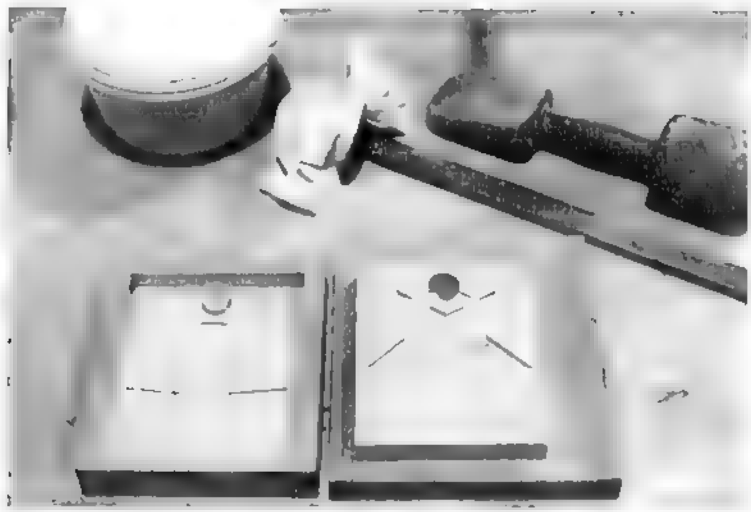


Figure 8-52
A sand form shaped by the corebox (in this case an H-Process mold) has been stripped from the corebox.

Figure 8-53
Locating pins and holes enable the molds to be stacked precisely in a simple fixture. A hacksaw blade has been used to create a sprue hole in the first mold. Stack molds on a plain slab of core sand to seal off the runnersphere in the first mold.

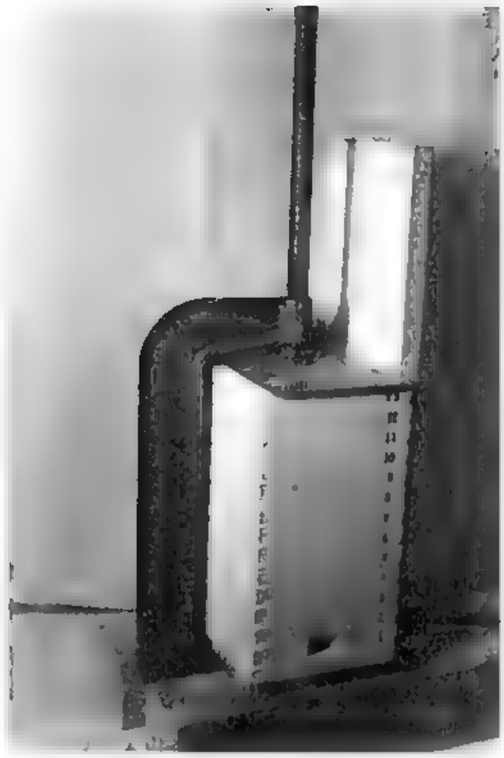


Figure 8-54
The backing plate is placed on the last mold and the string of molds is clamped carefully.

Figure 8-55
Pouring continues until the mold string will take no more metal.

12. Allow sufficient time for solidification.
13. Move the mold string to an area where the molds can be broken away without getting sand from these molds mixed in with the foundry sand.
14. Loosen the clamping fixture and break away the molds carefully so as not to damage the castings.
15. Sweep up and discard the sand—return all H-process articles, tools, and materials to their proper places.

CLAS PROCESS

The **CLAS process** is a new process for casting small (up to 3-pound [1.35-kilogram]), thin-walled ferrous and nonferrous parts in shell molds. The way in which this is done is quite unusual. Instead of pouring metal into the shell molds and allowing it to travel through the sprue, runners, and gates, filling the mold cavity under atmospheric pressure, CLAS-process shell molds are filled by submerging the drag side of the mold to a precise depth in molten metal and pulling metal through **drag ingates** into the mold cavity(ies) by means of a low vacuum applied to the cope side of the mold. A programmable controller instructs a completely automated casting machine to control submersion depth precisely and to remove the mold from the metal after the ingates have solidified. This occurs 5–30 seconds after the mold contacts the metal. The mold is then removed and conveyed to the shakeout area. Reversing the direction of pour in this manner prompts some individuals to refer to the CLAS process as the automatic counter-gravity casting of shell molds.

Although the CLAS process is presently limited to the production of small castings, larger castings will undoubtedly be produced as demands for larger equipment are met. Although surface finishes of CLAS process castings are not of the quality of investment castings, their cost is significantly lower. The greatest contribution of this new process to the technology of metalcasting may be its system of delivering clean metal to the mold.

Advantages and Disadvantages

In comparison with green sand molding, the CLAS process has a number of advantages and disadvantages. Some of the advantages are

- The process results in substantial reductions in sand, metal, energy, and labor costs for castings with up to ½-inch (13-millimeter) wall thickness.

- Steel castings with wall thicknesses to 0.400 inch (1 millimeter) can be produced at relatively low temperatures.
- Improvements in cutting-tool life of more than 100 percent can be expected because of the reduction of nonmetallic inclusions in the castings.
- The process results in castings with better surface finish.
- The process provides more castings per unit area of the mold.
- Gases cannot be injurious to the metal since they are drawn into the vacuum system.
- The elimination of sprue(s) and runners greatly increases yield.

Disadvantages of the CLAS process include

- Expensive, sophisticated, automated machinery is required.
- There are size limitations; presently the limit is 3-pound (1.35-kilogram) castings with wall thicknesses of ½-inch (13-millimeters).
- The sand used in shell molds is not reusable unless reclaimed.
- The energy for heating pattern and curing shell molds is expensive.

TEST YOUR KNOWLEDGE

Write your answers on a separate sheet of paper. Do not write in this book.

T-F **1.** Permanent mold casting is sometimes referred to as gravityless die casting.

2. Mold coatings for permanent mold castings in industry are usually sprayed liquid. A coating suggested for use in the school foundry is a layer of carbon deposited by ________.

3. When molten metal is forced into a permanent mold under pressure, the process is known as ________.

4. "Thin-walled molds made of dry, resin-coated sand" describes molds used in the ________ ________ process.

T-F **5.** The shell process is used in making cores as well as molds.

6. The lost wax process fits into the category of ________ casting.

7. The innovative metalcasting process that can produce castings so precise that machining is not required is ________.

8. The work time of lost wax investment should be neither more nor less than ________ minutes.

9. It is very important that wax patterns be ________ so that the pattern will be properly coated by the ________.

T-F 10. Ceramic shell molds are usually poured hot.

T-F 11. Little difference exists between the lost foam process and its forerunner, the full mold process.

T-F 12. The lost foam process lends itself to the production of lead castings.

13. Gating for the lost foam process is (simpler, more complicated) (choose one) than for green sand molding.

14. Pouring temperatures for lost foam molds, compared to those for green sand molds, are ________.

15. An innovative metalcasting process that does not require separate cores is the ________ ________ process.

T-F 16. The best way to apply the refractory coating to lost foam patterns is by dipping.

17. The first step in producing a V-process mold is to ________.

T-F 18. The flasks used in green sand molding are suitable for use with V-process molds.

T-F 19. Cores just made in a shell core machine could, if installed carefully, be used in a V-process mold.

20. V-process patterns are subject to little wear since their surfaces are never touched by ________.

21. Before the drag (or cope) of a V-process mold can be stripped from the pattern board, the ________ ________ valve must be turned off.

22. Shakeout in V-process is accomplished by turning the vacuum ________.

23. An innovative metalcasting process that enables a string of several dozen molds to be made with *one* pour is the ________ process.

24. The H-process is best known for its ability to increase ________.

25. Metal enters CLAS process molds from (above, below, the side). (Choose one.)

CHAPTER 9

The Future of the Metalcasting Industry

Processes That Will Increase in Use • Use of New Technology • Increasing Emphasis on High-Quality Castings • Protecting the Environment • Summary

CHAPTER GOALS

After studying this chapter, you should be able to:

1. Identify three metalcasting processes that will be used increasingly in the future.
2. Explain why there are no problems with gases produced by cores in the V-process.
3. Identify two new developments in permanent mold casting.
4. Indicate four present or potential uses for computers in foundry operations.
5. Point out the differences in the programming of manipulators and robots.
6. Characterize commercial quality castings of former times, and indicate some aspects of present-day quality that are expected to continue into the future.
7. Identify the factors that led to a serious effort to produce thin wall castings.
8. Explain what is meant by engineered materials.
9. Name a process used to ensure that metal gets from the ladle to the mold free of contamination by air.

TERMS TO KNOW (see Glossary)

Information processing	CAD	Al-Li alloys
Third world countries	CAM	Metal matrix composite
Manufacturing	CNC	Plasma
Computer	Computer vision	Net shape
Manipulator	AI	Surface finish
Robot	Thin-wall casting	EPA
Graphite molds	Engineered material	Hazardous waste
Near-net shape	Ductile iron (DI)	OSHA
DCC-CMM		

The metalcasting industry in this country has seen many changes in recent years. Some of these occurred because of the vigor of the industry and the new developments it has fostered. Some changes were responses to new governmental regulations and competition from abroad; these changes have resulted in fewer foundries and fewer employees. But the foundries that remain are stronger for having coped with all these changes and their employees are better trained than ever before.

Some forecasters predict that the United States will become a leader in **information processing,** with other nations (particularly **third world countries**) becoming preeminent in **manufacturing.** Manufacturing is the area in which this country has excelled for many years, and foundrymen seem determined to keep it that way by maintaining an industry that is basic, vital, dynamic, and interesting.

So what can be said with certainty about the future? Only that the types of changes that have taken place in recent years will continue. Some of the newer processes will be used to make tons of castings without eliminating the more conventional metalcasting processes. Methods of producing metal castings that are unknown today will be developed. **Computers, manipulators,** and **robots** will find increasing use in all aspects of the metalcasting process. The industry will continue to find ways of responding to customers' demands for zero-defect castings, which will be produced in clean, quiet, totally automated plants that specialize in specific types of castings. There will be a continued concern that the metalcasting industry does its part in protecting the environment.

There will be a persistent need for technically competent young people who enjoy solving problems to enter the metalcasting industry. Opportunities for exciting careers will continue to exist.

PROCESSES THAT WILL INCREASE IN USE

New metalcasting processes, unknown today, will undoubtedly appear on the horizon as we move into the future. Maybe you will play a part in such development. How exciting that would be! But what of the recently developed innovative processes? Will they prosper for a time and then fade away? Alternatively, will they flourish to the point where they will replace and eliminate some of the conventional metalcasting processes?

In most instances, neither of the above will happen. Most of these processes will gradually find their "niche" within the industry by producing castings more *efficiently* than possible with any other process. Six innovative processes that seem to be moving fastest to achieve that status are discussed here.

Lost Foam

By whatever name it eventually is known, there is a substantial amount of interest in this process, and it appears to have great potential for producing complex, highly accurate castings at low cost. Lost foam procedures are so different from those of green sand molding, and the process involves such different equipment, that a strong commitment is required for a foundry to give it a fair try. Even with a strong commitment, it must be realized that this "user-friendly" process has its own set of rules, which must be followed very carefully if success is to be achieved. Problems associated with the process will be solved as more foundries begin to use it. There seem to be no uncontrollable hazards associated with the process. It seems clear that the lost foam process will be used to make a great many castings in the future.

V-process

There is much about the V-process that fits into visions of the "foundry of the future." Such a foundry should produce high quality castings in a comfortable hazard-free environment at competitive costs, without adversely impacting the environment. Because of the hardness and stability of the mold, V-process castings have excellent dimensional accuracy with smaller-than-normal or no machining allowance. Because the dry, room-temperature mold of finely packed sand acts as an insulator, V-process castings cool much more slowly, and both the mechanical properties and internal integrity of the casting are enhanced. Because the process uses dry, free-flowing, unbonded sand, there is little about the sand system to control except fines; if they are controlled, there are *no* sand problems in V-process. This is in contrast to green sand molding, where close control of the sand is critical to successful operation. Because extremely fine sand or a refractory wash (sprayed over the plastic film) is used in the V-process, the surface finish of castings is excellent. Although sand cores must be washed to prevent metal penetration, V-process castings have no core gas defects since gases are pulled off by the vacuum. Because there is very little heavy equipment in a V-process foundry, there is little noise. Because V-process sand is unbonded, the working environment is quite clean. Because V-process sand is reused, there are no environmental problems of disposal. Although V-process is not practical for all castings (one limitation being that recesses cannot be deeper than their width)

and does not lend itself to high production (60 molds per hour is a high rate for the process), it seems likely that more and more of the castings produced in the future will be made by the V-process.

Permanent Mold Casting

New developments continue to take place in the permanent mold casting process. Brass castings, such as plumbing hardware, that typically have been produced as sand castings in the United States are being produced in Europe in permanent molds. Such castings have finer grain structure, cleaner metal, and better surface finish and are cast to closer tolerances than similar castings made in sand molds.

Another evolving technology in permanent mold casting is the use of **graphite molds.** Molds are fabricated of premium, high-density graphite with extremely low porosity. Machining of graphite molds is much easier and faster than machining of metal molds. With the zinc-aluminum alloy (ZA-12), such molds can produce from 20–50 thousand castings that have excellent surface finish and are dimensionally accurate to the point of qualifying as precision castings.

Research has begun on the use of aluminum alloys and vacuum-assist pouring. Projected growth for this specialized area of permanent mold casting is good.

Yet another area of evolving technology is the production of iron castings in permanent molds. In the relatively few places where this is being done, castings are highly accurate and of very clean metal with superior mechanical properties and a carbide-free surface finish. Any machining that is required can be done faster with much less tool wear. All these advantages are achieved with greater yields and fewer environmental problems. Earlier attempts to produce iron castings in permanent molds were unsuccessful because of poor mold life. Pouring systems that automatically dispense just the right amount of iron necessary to fill the mold and shield the molten stream of metal from the atmosphere during pouring are expected to be in use before long.

Investment Casting

Investment casting will see increased use in the future. As additional, hard-to-machine alloys are developed and complex castings with **near-net shape** are demanded, there will be additional need for castings made by this process. Investment castings will replace sand castings, weldments, forgings, and components that require substantial machining or grinding. The electronics, defense, and aerospace industries are heavily dependent on the investment casting process, because its sophisticated utilization of materials can provide reduced size and weight without loss of strength. This alone will guarantee the continued use of this process.

Die Casting

The process of die casting has evolved from an art to a science in recent years. It has seen the development and utilization of a great deal of new technology, and it was the first of the various metalcasting processes to use robots. In spite of this, the die casting industry is, perhaps, most affected of all the metalcasting processes by foreign competition. A number of strategies are in place to combat such competition and to expand the sales of U.S. die casters. These include a die caster certification plan and grants to develop new markets and advance current technology. The Die Casting Research Foundation (DCRF), the research arm of the American Die Casting Institute (ADCI), has been revitalized. Such aggressive action on the part of the industry, together with the ability of the die casting process to produce dimensionally accurate castings with superior surface finish on a rapid and consistent basis, makes die casting a logical candidate for producing metal castings well into the future.

CLAS Process

The CLAS process seems to have made a significant contribution to the technology of metalcasting through its proven system of delivering clean metal to the mold. A shell mold, sprue side down, is placed in contact with molten metal. When a vacuum is applied to the top of the mold, atmospheric pressure forces metal up into the mold. But there are many other aspects of this process that suggest it will find increased use in the future.

CLAS castings are quite free of nonmetallic inclusions, which greatly reduces machining costs through extended tool life. The process lends itself to the automated workplace of the future. Gases that are formed during the process are drawn into the vacuum system, resulting in a highly desirable working environment for the limited number of operators that are required. Producing steel castings with wall thicknesses as thin as .040 inch (1 millimeter) is remarkable in itself, but to be able to accomplish this using metals at relatively low temperatures is even more impressive. Low superheat produces less gas for steels to absorb, resulting in fewer globular solid oxides being formed as the metal cools in the mold. Substantial increases in yield and reduction in sand, metal, energy, and labor costs are other attributes of the CLAS process that appeal to metalcasters.

It seems likely that the automatic counter-gravity casting of shell molds will see much use in the future, that larger castings will be produced as manufacturers respond to a demand for larger equipment, and that the pouring technique involved in the CLAS process may be adapted to other present and future metalcasting processes.

USE OF NEW TECHNOLOGY

In addition to increased use of some operational metalcasting processes (and the prospect of others presently in development), foundries of the future will become increasingly involved in use of computers, manipulators, and robots.

Computers

The U.S. metalcasting industry is behind most other industries in utilizing computers. This, of course, means that there is great opportunity for the adoption and adaptation of computer technology. For many years, computers have been used for making up charges and controlling melting. Computers are just starting to be used to simulate metal solidification in certain metalcasting processes based on heat-transfer programs. Optimal process parameters are thus determined prior to the actual pouring of metal. Use of such simulation will continue. However, in the future, additional aspects, such as temperature changes that take place in the mold as it fills and the convective flow of metal as it solidifies, will be an integral part of the design. This development will assist greatly in the production of high quality castings.

Direct computer-controlled coordinate-measuring machines (DCC-CMM) are presently being used for inspection of individual parts to an accuracy of 0.0001 inch (0.0025 millimeter) in about 2 percent of the time formerly required (Fig. 9-1). Such machines have many other uses, such as reviewing tool wear, providing dimensional verification prior to shipping when required by certain customers, and conducting dimensional capability studies. Increased use of computer-controlled equipment even more sophisticated than this will be seen in the future.

In some patternmaking shops, **computer-aided drafting (CAD)** is used in the design of some patterns (Fig. 9-2). Cutter tool-paths are then established with **computer-aided manufacturing (CAM)** (Fig. 9-3). A numerical controlled-machining output is then generated, which conveys instructions to **computer-numerical-controlled (CNC)** machine tools (Fig. 9-4), which cut the production pattern to shape. The dimensional accuracy and consistency of this approach will find increasing demand in the future.

An emerging technology is the combined use of television and computer technologies called **computer vision.** Such equipment has been used for the rapid inspection of castings (20 per minute) to accuracies of 0.002 inch (0.05 millimeter). Computer systems will also find increasing use in such areas as inventory control and the scheduling of labor and machinery to meet delivery dates.

Foundries of the future will use computers with **artificial intelli-**

Figure 9-1
A direct computer-controlled coordinate-measuring machine (DCC-CMM). Notice the casting under the probe on the layout table to the left and the computer console and the printer on the right.

Figure 9-2
Computer-aided drafting (CAD) design stations such as this one enable the drawing of a foundry pattern to be enhanced with such parameters as draft, shrinkage, and machining allowances quickly and accurately.

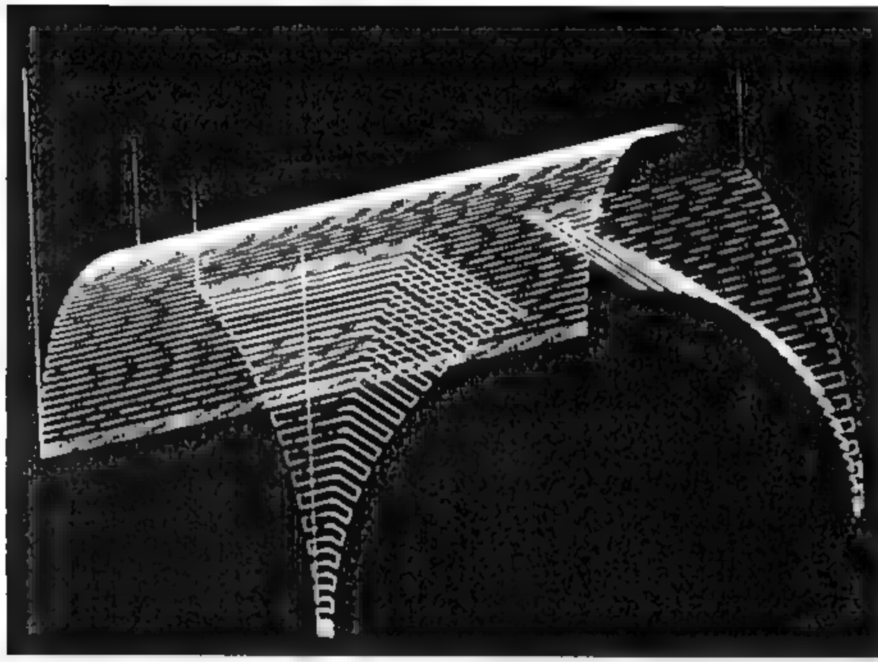


Figure 9-3
After the computer-generated model of a pattern has been developed, a tool-path for producing the surface of the pattern can be displayed on the monitor screen as shown here.

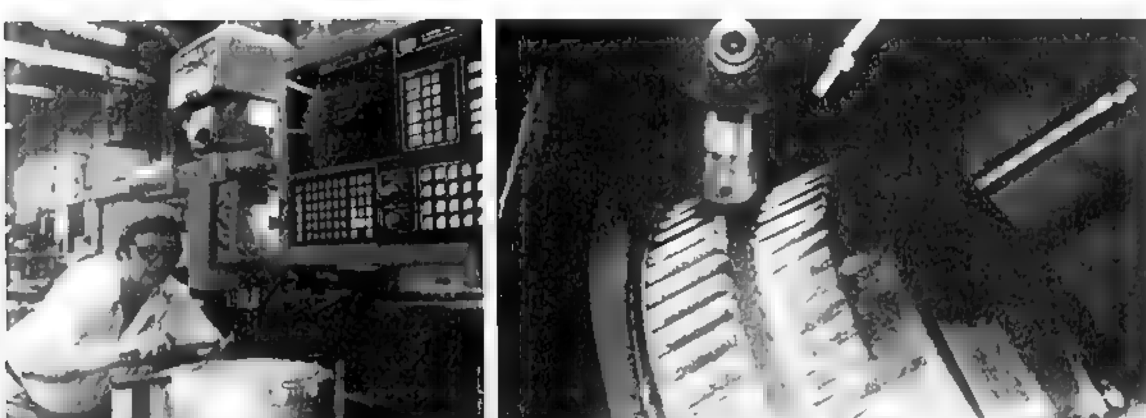


Figure 9-4
Left: Operator setting up a computer-numerical-controlled (CNC) milling machine.
Right: Close-up view of actual machining.

gence (AI). The computer, equipped with vast amounts of accumulated knowledge from teams of experts and using sophisticated problem-solving techniques, will be able to respond to *spoken* questions and provide answers to complicated and interconnected problems.

It appears that in the future, almost every aspect of a foundry's operations will benefit from the use of computers.

Manipulators

A **manipulator** (Fig. 9-5) is a robot-like machine that requires a more intimate relationship between man and machine than does a robot. It can be anchored to the floor or mounted on a wheeled platform. It has a work-

Figure 9-5
A manipulator being used in a shakeout area to remove castings from flasks and to place them on a conveyor.

ing arm that moves in six or more axes. This arm is normally fitted with grippers or tools. A manipulator operator, moving the master-arm of the manipulator, can control the machine *manually.* If *semiautomatic* or *automatic control* is desired, the operator teaches the manipulator by setting certain controls and guiding the manipulator through a sequence of motions with the master-arm. The manipulator will repeat these motions automatically. Manipulators are finding their way into foundry operations. At present, manipulators have proven to be useful in shakeout operations for such things as picking castings from flasks, removing sand, separating runner systems from castings, and hanging castings on conveyer hooks. In cleaning applications manipulators remove excess metal and surface sand inclusions with wheel or belt grinders. In melting, manipulators are used in furnace charging, slag removal and pouring. It can be seen from this that manipulators lend themselves to use in harsh environments.

Robots

Robots (Fig. 9-6) are similar to manipulators in some respects but quite different in others. Like manipulators, they are used to replace humans where working conditions are hazardous, tedious, or monotonous. Being somewhat more sophisticated than manipulators, robots tend to be used in less harsh environments. Robots can be mobile as well as stationary. They are programmed to function in the desired manner by a computer programmer.

Since 1962 robots have been used in the die casting process, resulting in dramatic increases in production. Typical uses are spraying die lubricant, unloading the machine, quenching the part, and placing the part in a trim press and then onto a conveyer belt or into a container.

Robots have been used in the investment shell casting process since the 1970s for the uniform coating of wax clusters with slurry, stuccoing them, and placing the clusters on drying racks.

Robots are now being used in a number of metalcasting processes or operations such as green sand molding, coremaking, and permanent mold casting. They are also being used for inspection (sorting good castings from those with defects), for transfer (moving cores into storage and from there to molding areas as needed), and for "pick and place" applications such as core setting.

INCREASING EMPHASIS ON HIGH-QUALITY CASTINGS

In former times, some foundries could operate with the belief that quality should not stand in the way of on-time delivery and profitability. Commercial-quality castings were the norm. Inspection was largely lim-

Figure 9-6
Using a robot to build ceramic shells over wax patterns results in very uniform coatings of slurry and stucco.

ited to what could be seen visually. Chemical and mechanical properties, if required, were determined from a separately cast test bar. A certain percentage of scrap was budgeted into the overall production. Now (and certainly in the future) foundries will prosper only if they can produce high-quality castings at competitive prices. The technology exists to inspect and test castings in a wide variety of ways to accurately determine

quality. There will undoubtedly be even more sophisticated testing equipment developed in the years ahead. Additionally, castings made by many competitors in other parts of the world are of improved quality, which must be met or exceeded. In the race for higher-quality castings, the categories of thin-wall castings, engineered materials, near-net shape, and better surface finish will all play important parts. Each of these is described below.

Thin-wall Castings

The worldwide oil situation has produced great pressures for improved automobile fuel economy, resulting in the production of smaller, lighter cars. This has prompted a major effort to reduce automobile weight by substituting plastics, aluminum, and other lightweight materials for conventional materials. Another approach has been to produce lighter cars by reducing the weight of iron castings. A prime candidate for this type of weight reduction is the engine, particularly the cylinder block. An in-line six-cylinder cast iron cylinder block used to weigh around 180 pounds (81 kilograms). Efforts were focused on reducing this weight as much as possible. Through the use of a new design that eliminated metal wherever possible and a thorough process-control program governing molding, coldbox core technology, and melting, one company has been able to demonstrate the consistent production of **thin-wall** engine blocks with a 20 percent reduction in weight at a total scrap rate of 3 percent or less (Fig. 9-7). It is expected that efforts in the area of thin-wall castings will become increasing important as the metalcasting industry continues to respond to customer demands for higher quality castings.

Engineered Materials

Gray cast iron, steel, and several aluminum- and copper-base alloys formerly made up most of the tonnage of castings that were poured. Now and in the foreseeable future, materials are being developed **(engineered)** to possess mechanical properties that are not available in the materials

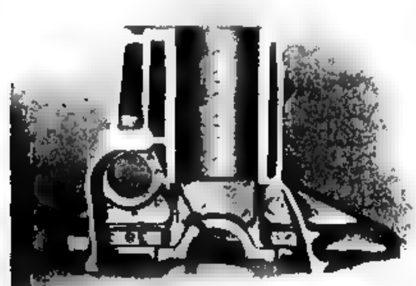


Figure 9-7
The cylinder block has been cut to reveal uniformly thin walls, resulting in substantial weight reduction. Such precise castings require thorough control of molding processes and core technology.

listed above. For example, gray iron with superior machinability and compressive strength is a very useful material for many products. However, its lack of ductility renders it useless for many other products. Adding a small amount of magnesium to gray iron causes the carbon in the iron to form into small spheres, resulting in nodular iron, known as **ductile iron.** Compared with gray iron, ductile iron has greater stiffness, strength, and shock resistance. Of even more importance is the ductility possessed by the material. It has excellent casting characteristics and lower weight and processing costs.

Among aluminum alloys, research has developed **Al-Li** (aluminum-lithium) alloys that are expected to replace presently used alloys in the aerospace industry. The 10-percent weight reduction of such alloys amounts to about 10 tons in a Boeing 747.

Some pioneering work is being done with **metal matrix composites** (fiber reinforced metals). Fibers of material such as graphite or silicon carbide incorporated into a metal matrix produce composites with high tensile strengths, improved properties at elevated temperatures, and a possible weight reduction.

Not only will increased attention be given in the future to materials that are engineered to provide certain properties, but also to the melting and pouring of all metals. Pioneering work is being done with **plasma** melting technology in the melting of steel and plasma-fired cupolas in the melting of iron. Pouring temperatures will be more closely controlled. Filtering metal will become standard practice, as will automatically controlling the quantity and pouring rate of metal poured. There will also be increased use of various techniques of getting the metal from the ladle into the mold free of air contamination, such as the CLAS process.

Near-Net Shape

The ultimate goal of the metalcaster is to produce castings that exactly match the dimensions on the drawing and need little or no additional processing to be put into service. In the early 1980s the term **net shape** was attached to this goal. Although net shape is a worthy goal, it seems more realistic at this juncture in the evolution of metalcasting to work for the more attainable goal of **near-net shape.** The ability to cast parts to net shape or near-net shape has many advantages. Some of these are maximum yield, minimum material handling, minimum returns, and maximum profits. Metalcasting processes that are inherently capable of producing castings with near-net shape are processes that will flourish in the future. Of those presently in use, permanent mold, die casting, investment casting, lost foam, CLAS, and V-process seem to offer advantages in near-net shape manufacturing. Any newly developed metalcasting processes will focus on near-net shape as a primary objective.

Better Surface Finish

Surface finish of a casting, always a concern of metalcasters, is coming to be a prime criterion in the search for better castings. Permanent mold casting, die casting, and investment casting have enjoyed advantages over other metalcasting processes on the important criterion of surface finish. However, the V-process and the lost foam process can both point to highly acceptable surface finishes on castings produced by those processes. The interest in improved surface finish is expected to continue in the years ahead.

PROTECTING THE ENVIRONMENT

In former years, foundries, like all other manufacturers, gave little thought to the way some of their byproducts affected the environment. All that has changed. Foundries, together with their fellow manufacturers, are doing their best to be responsible agents in protecting the environment and are working diligently to provide healthy and safe places to work.

The disposal of sand, a primary material for certain metalcasting processes, is a problem peculiar to foundries. Hazardous wastes, water, and the working environment are matters of concern to all manufacturing.

Increased Use of Reclaimed Sand

Sand is one of the most-used materials in the production of metal castings. In sand foundries, 70–80 tons of material (much of it sand) is used to produce *1* ton of castings. Most of the sand has been silica. The fact that silica sand is one of the most plentiful materials on the earth's surface has been a happy coincidence. Over the years, its availability has encouraged not only its use but also its waste. Now that health problems have been shown to be associated with silica sand, there is some movement in the industry toward using other, safer, but less available and more expensive sands.

The rising cost of transporting sand to the foundries and eventually to disposal sites has driven up the cost of sand. Also, regulations of the **Environmental Protection Agency (EPA)** control closely the disposal of hazardous and nonhazardous wastes. If wastes cannot be shown to be free of hazardous materials, the cost of disposing of such materials increases dramatically. All these factors have had substantial impact on the foundry industry's use of sand. Conservation has become extremely important. As a result, now there is substantial interest in processing sand for reuse, and sand reclamation is an emerging technology.

Handling Hazardous Wastes

Management of its **hazardous wastes** is now one of the most important environmental issues faced by industry and will continue to be important in the future. Even though foundries in general are not considered to be large generators of hazardous wastes, they are subject to all general and some special environmental regulations. Wastes are checked for ignitability, corrosivity, reactivity, and toxicity, any of which would characterize the waste as hazardous.

Hazardous wastes will likely be only a small part of the total wastes generated by a foundry. Nonhazardous foundry wastes are also generated. These can often be used in a constructive manner for such things as road building, construction fill, and landfill cover.

Improved Stewardship of Water

Since water is one of the most plentiful of this country's natural resources, it has, for the most part, been taken for granted. In recent years, however, our society has come to realize that heroic efforts must be made to control and, if possible, reverse the pollution of our streams, rivers, and lakes. All industries (including foundries) have been heavily criticized as major offenders in the pollution of water. Governmental regulations now exist that will force industries to exercise good stewardship of the water they use. Since industry is a major, but not the only, offender in this matter, it is important that all of us recognize the problem and accept responsibility for anything we can do to improve the situation.

In the case of foundries, each must set up a waste-water treatment program that will ensure that it is in compliance with the EPA Foundry Effluent Guidelines.

Maintaining a Healthy Work Atmosphere

For many years foundries have had a reputation for being less-than-desirable places to work. This view is changing and will continue to change until most foundries are air conditioned, environmentally controlled plants, with few hazardous jobs. Concern for the workers' safety is not new. Safety glasses, hearing protection, hard hats, steel-toed shoes (with or without metatarsal arch protectors), respirators, gloves, protective clothing, and so on have been a part of the industrial workplace for a number of years. So have safety lanes, safety rails, and load balancers (Fig. 9-8) for lifting heavy loads easily. The emphasis now is on clean, temperature-controlled air and adequate lighting, and on providing training for workers in the safety precautions they should take with properly labeled hazardous materials in the workplace. In addition to personal protection of all kinds, safety training films and slides are readily available to assist companies with developing effective safety programs. The **Oc-**

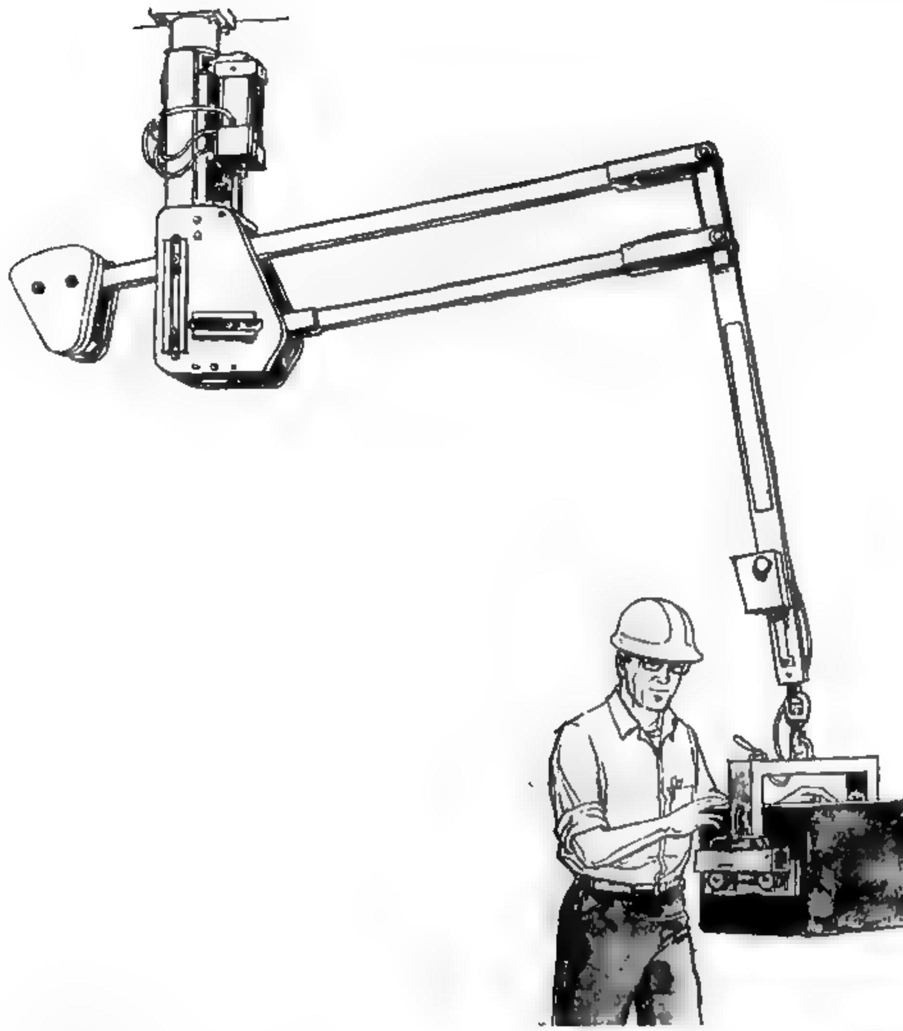


Figure 9-8
A load balancer enables heavy or awkward objects to be handled easily and safely.

cupational Safety and Health Administration (OSHA) mandates that all feasible engineering know-how be used to eliminate hazards from the workplace. The establishment of work environments that are healthy and safe will continue to be a top priority in foundry operations of the future.

SUMMARY

The foundry industry in this country has a grand tradition that has made it unique among industries. Its uniqueness lies in the *people* who make up the industry. Despite new technology, an old-fashioned feeling of family persists. There is a strong commitment on the part of those within

the industry to regain world leadership by developing and using superior technology. If you enjoy challenges and thrive on opportunities to use your creativity and ingenuity in solving real problems on a day-to-day basis, perhaps you should consider pursuing a career in this dynamic industry. If so, you will want to acquire adequate training, for the foundry of the future will have little need for unskilled or semiskilled personnel. It will, however, require well-trained people with a wide variety of talents: pattern and die makers; sand, melt, lab, and safety technicians; process-control, quality-control, production, metallurgical and chemical engineers; technical sales representatives; managers of all kinds; and executives. You might be very happy working in one of those positions. Think about it.

TEST YOUR KNOWLEDGE

Write your answers on a separate sheet of paper. Do not write in this book.

1. Some predict that the United States will soon become predominantly involved in __________ processing.
2. Brass castings (such as plumbing hardware) that normally are cast in the United States in __________ molds are being produced in Europe in __________ molds.
3. Most permanent molds are made of metal but some are now being made of __________.
4. Due to extended mold life, some successful use is being made of the permanent mold process to cast __________.
5. T-F The U.S. foundry industry is *behind* most other industries in the use of computers.
6. Where harsh environments are involved (manipulators, robots) (choose one) are better than (manipulators, robots) (choose one).
7. The first metalcasting process in which robots were used was __________.
8. CAD stands for __________.
9. The new lightweight alloy that could reduce the weight of a Boeing 747 by 10 tons is an __________ lithium alloy.
10. Three metalcasting processes that seem to have an advantage in producing castings to near-net shape are __________, __________, and __________.

11. Two processes that typically produce metal castings with superior surface finish are __________ and __________.

T-F 12. Currently, interest in sand reclamation is quite limited.

T-F 13. All foundry wastes are considered hazardous.

14. The federal agency charged with ensuring the safety and health of an industrial employee and that of the workplace is the __________.

Glossary

AFS SAND SPECIMEN: A cylinder of foundry sand (2 inches in diameter and 2 inches long) produced by placing about 175 grams of tempered foundry sand into a specimen tube and giving it three rams with a sand rammer.

AI: Artificial intelligence; the capability of a machine (computer) to emulate human reasoning.

AL-LI ALLOYS: Light, strong alloys produced by combining lithium with aluminum.

ASSEMBLY: A finished component consisting of two or more parts.

AVERAGE MOISTURE CONTENT: Even properly cured lumber takes on or gives off moisture from the air around it until its moisture content equals that of the air. In much of the United States, the average moisture content is 8 percent. However, in the desert states of Nevada and Arizona, it is 6 percent, and along the coast of southern California and the southeastern states, it is 11 percent.

BELLOWS: A bag-like device operated with both hands to produce a current of air; some bellows are mechanically operated.

BENT HANDLE CRUCIBLE TONGS: Hot crucibles must be handled with crucible tongs. Bent handle crucible tongs are designed to be used by two persons who are handling large crucibles.

BINDER: Any material added to foundry sand to cause sand grains to stick together. In the case of oil-tempered (waterless) foundry sand, the binder is a reddish, flour-like material.

BLIND RISER: A riser that does not extend to the top surface of the cope.

BLOW: A casting defect caused by trapping gas in molten or partially molten metal.

BOND: A material such as clay that, when added to a sand mixture gives a

cohesive characteristic to the sand mixture when the sand mixture is tempered with water.

BOT: A cone-shaped piece of soft clay that is forced into the tap hole of a cupola to stop the flow of iron when operating a cupola in an intermittent tapping mode. It hardens immediately and is chipped out (like breaking a coffee cup) when more iron is needed.

BUCKLE: Defect on a casting surface, appearing as an indentation resulting from an expansion scab.

BULB: As applied to risers, the lower end of a side riser. It should be rounded to the radius of the riser.

BULB SPONGE: A soft brush attached to a rubber bulb containing water; used when making green sand molds with any clay-bonded sand to which water is added to develop plasticity and to make the sand mixture moldable. A bulb sponge is used to add a small amount of moisture around a loose pattern before the pattern is rapped and pulled.

BURN IN: A surface defect caused by a thin layer of sand fusing with the metal surface of the casting, forming a glass-like and possibly pock-marked surface.

BURN ON: Expression denoting adhesion of sand to the casting, usually due to the metal penetrating into the sand. Grinding is necessary to remove the defect.

BUSHING: As applied to flasks, replaceable sleeves installed in the flask "ears" of the cape portion of a flask.

BUTTON: The metal found at the entry end of a lost wax investment flask after the cavity has been filled.

CAD: Computer-aided drafting.

CAM: Computer-aided manufacturing.

CARRIER: *See* PATTERN CARRIER.

CATALYST: A substance that initiates a chemical reaction.

CAVITYLESS CASTING: The first patented metalcasting process to use patterns of expandable polystyrene. Molds are made in the standard way (using green sand) except that the pattern is left in the mold. Metal poured into the mold vaporizes and replaces the foam pattern, producing a casting identical to the pattern.

CHANNEL INDUCTION FURNACE: An electric furnace (generally larger than the coreless type) which has a coil around a metal core near a U-shaped channel at the bottom of the furnace. The electrical current passing through the coil sets up magnetic fields. Voltage is induced and a flow of electrical current follows. The resistance of the charge metal to the current flow produces sufficient heat to melt the metal.

CHAPLETS: Metal supports (often similar to a two-headed nail) used to hold cores in position in those molds in which core prints cannot be used.

CHARGE METAL: A given weight of metal to be melted.

CHARGING DOOR: Opening through which the furnace is charged.

CHILL: Device (usually metal) used in molds to assist in controlling shrinkage and achieving directional solidification. *See also* EXTERNAL CHILL; INTERNAL CHILL.

CHOKE: The smallest cross-sectional opening in a gating system. This is often the bottom of the sprue, but chokes are sometimes located in the runner(s) between the sprue base and the first gate.

CLAS PROCESS: A process that produces castings by submerging the drag side of a shell mold into molten metal and drawing metal through ingates (in the drag) into the mold cavities by means of a vacuum applied to the cope side of the mold.

CNC: Computer-numerical controlled, a designation for machine tools (lathes, mills, etc.) that can function from instructions received directly, through a computer-to-computer link, or indirectly, from a paper tape or a computer disk.

COLD BOX CORE: Vapor-cured core made of sand and a binder system that hardens very quickly in the presence of a toxic gas, such as dimethylethylamine (DMEA), or a gas with an extremely disagreeable odor, such as sulfur dioxide (SO_2).

COLD-CHAMBER DIE CASTING MACHINE: A die casting machine containing a shot sleeve into which molten metal is ladled, after which it is forced by a plunger into the die at high pressure.

COLD OR (DEAD) RISER: Riser located downstream from the mold cavity. Such risers require special treatment of some kind (insulated riser sleeves or hot topping) if they are to function properly.

COLD SHUT: A defect in which two streams of metal do not unite thoroughly in a casting.

COLD FLOUR PASTE: An adhesive traditionally (and still) used in "pasting" core parts together into a core assembly.

COMBINATION DIE: A die casting die having cavities of different shapes that produce several parts for an assembly.

COMPACTIBILITY: As applied to sand testing, a test widely used in daily operations to supplement standard moisture tests and to monitor moisture additions at the muller. This test is most like the hand-squeeze test of an experienced molder.

COMPOSITE PLATE: A pattern plate that provides essential support to some portion of the loose patterns mounted on it. In many cases, the loose patterns may be too fragile to be rammed up successfully without the support provided by the plate.

COMPUTER: A programmable electronic device that can store, retrieve, and process data.

COMPUTER VISION: The ability of a machine to "see." *Image-processing* equipment captures a visual scene in analog form, converts it into digital electronic signals, and stores it in the memory of a computer. Once stored, an *array*

processor manipulates the digital data according to sophisticated vision algorithms, conditioning the data for display on TV-type monitors and storing it for further use. This is all accomplished in fractions of a second. A typical computer vision system provides functions such as feature extraction, pattern recognition, image analysis, and image enhancement. The use of computer vision systems in the foundry for such tasks as visual surface inspection, part identification, go/no-go gauging, defect location, and so on, is expected to increase dramatically in the future.

CONTINUOUS MIXERS: Auger-type mixers that are designed to add binders and catalysts in the mixing tube a short distance ahead of the discharge end. Such mixers are commonly used with chemically bonded sands in which bonds start to develop as soon as binders and catalysts are mixed.

COOLING SHED: An area in most commercial foundries in which castings cool before and/or after shakeout, before going to the cleaning area.

COPE PLATE: The plate to which is attached (to its top side only) that portion of the pattern and that part of the gating system that are in the *cope* part of the mold. The underside of the cope plate is commonly strengthened with heavy ribs. Such a plate is designed to be used in a cope machine that makes only the cope half of a mold. *See also* DRAG PLATE.

CORE BLOWER: A machine that uses a blast of air to pack sand into a corebox.

COREBOX: A structure of wood, metal, or plastic containing a cavity that is designed to produce a dry-sand core.

CORE DRIER: Metal (or sand) supports used to maintain the shape of oil-sand cores during baking.

CORELESS INDUCTION FURNACE: An electric furnace in which water-cooled coils that carry electrical current surround the charge metal. Magnetic fields are established and voltage is induced followed by a flow of electrical current. The resistance of the charge metal to the current flow produces sufficient heat to melt the metal.

CORE PLUG (CORE STICK): An exact duplicate of the required core made of a durable material such as wood. Core plugs are used to produce complicated internal shapes in plastic coreboxes.

CORE PRINTS: Impressions produced in a mold at points where cores are to be supported.

CORE STICK: *See* CORE PLUG

COVER FLUX: A material added to metal being melted in a crucible that unites with impurities and other foreign matter, and that, as it floats on the surface of the molten metal, protects that surface from oxide formation.

CREEP: To slip or gradually shift position.

CRUCIBLE: Container made of clay-bonded graphite or carbon-bonded silicon carbide, used to melt metals in crucible furnaces. Crucibles are standardized in shape and size. The most common shape is *bilge.* The number (size) of a crucible represents its capacity in pounds of aluminum.

CRUCIBLE FURNACE: Furnace in which metal is melted in crucibles.

CRUCIBLE SHANK: Specially designed device into which hot crucibles are placed so that their contents can be poured safely and without damage to the crucibles.

CRUCIBLE TONGS: Specially designed device for handling hot crucibles safely and without damage to the crucibles.

CUPOLA: Stack-type melting unit in which metal is melted in direct contact with the fuel.

CUPREX 100: A proprietary cover flux for use with red brass.

CUPRIT 49: A proprietary cover flux for use with yellow brass.

CURE TIME: As applied to shell coremaking, the time the sand shell remains in the hot corebox after the box has been emptied of the sand (from the center of the core) that was unaffected by the heat of the corebox.

CUT: Defect in a casting resulting from erosion of the sand by the molten metal as it fills the mold.

DCC-CMM: Direct computer-controlled Coordinate-measuring machine.

DEGASSER: A material (solid or gaseous) used to purge molten aluminum of hydrogen gas. If this procedure is not done, the entrapped hydrogen gas causes porosity defects in the castings.

DEOXIDIZE: The process of adding a special material to a molten metal, which will cause the metal to give up much of the oxygen that was absorbed by the metal during the melting process.

DIE CASTING: The production of accurately dimensioned, sharply defined castings by forcing metal (under high pressure) into long-life molds called *dies.*

DIRECTIONAL SOLIDIFICATION: The solidification of a casting beginning at the sections farthest from the supply of molten metal and moving toward that supply.

DOME: As applied to risers, the top end of a blind riser. The dome should be rounded to the radius of the riser.

DOUBLE SHRINK: When *casting* a *metal* pattern (for use in production molding), the wooden pattern must be made larger than the metal pattern to allow for the shrinkage of the metal used to cast the pattern as well as the shrinkage of the metal that will be used to make the casting. These two allowances are known as *double shrink.*

DRAFT: The taper on vertical edges of a pattern that allows easy withdrawal of the pattern from a sand mold.

DRAG: That portion of a flask that is on the bottom when the mold is poured.

DRAG INGATES: As applied to the CLAS process, the openings in the *drag* side of a CLAS process shell mold that is submerged in molten metal. The metal is drawn into the mold cavity through these drag ingates by vacuum applied at the top or cope side of the mold.

DRAG PLATE: The plate to which is attached (to its top side only) that portion of the pattern and those parts of the gating system that are in the *drag* part of the mold. The underside of the drag plate is commonly strengthened with heavy ribs. Such a plate is designed to be used on a drag machine that makes only the *drag* half of a mold. *See also* COPE PLATE.

DRAWBACK: A loose piece of a pattern that must be removed before the pattern is pulled.

DRAW SCREW: A rod with wood screw-type threads on one end for wooden patterns (or American National threads for metal patterns) that can be screwed into the pattern and thus serve as a temporary handle to facilitate removal of the pattern from the sand mold.

DRAW SPIKE: A sharp-pointed rod that can be driven into a wooden pattern and thus serve as a temporary handle to facilitate removal of the pattern from the sand mold.

DROP: A defect caused by chunks of sand falling into the mold cavity and preventing metal from completely filling the mold.

DROSS: Metal oxides in or on the surface of molten metal.

DRY SAND CORE: Any core that is not a green sand core.

DUCTILE IRON (DI): An engineered material produced by adding a small amount of magnesium to gray iron. The carbon in the iron thus forms into small spheres and produces a metal with good ductility, stiffness, strength, and shock resistance.

ENGINEERED MATERIAL: Materials developed as a result of research to provide desirable mechanical properties not available in traditionally used materials.

EPA: Environmental Protection Agency, an agency of the federal government charged with protecting the environment.

EXPANSION SCAB: Rough thin layer of metal partially separated from the body of the casting by a thin layer of sand and held in place by a thin vein of metal.

EXTERNAL CHILL: Heat-conducting material (normally metal but possibly a special wash) that is placed in the mold in such a way that it serves as the mold wall. Such chills are located where rapid cooling is desired. *See also* CHILLS; INTERNAL CHILLS.

FIN: Thin projection of excess metal on a casting.

FIRIT: A proprietary coating material. It comes in powder form and is mixed with a specific amount of water and allowed to stand (to develop the bond) for a given amount of time before use.

FLASK: A metal (or wood) box (normally rectangular) without a top or bottom that is used to hold the sand in which a mold is made. The flask usually consists of two parts, cope and drag.

FOUNDRY NAILS: Long, thin nails specially made to be pushed into sand molds in areas that require strength.

FLUIDIZE: The process of adding a special material to increase the fluidity of molten metal.

FLUX: A material added to molten metal that unites with impurities to form dross or slag, which rises to and floats on the surface of the metal and is removed by skimming before the metal is poured.

FRONT SLAGGER: A specially designed spout at the tap hole of a cupola that segregates slag from iron as molten material from the cupola flows through the spout.

FULL MOLD PROCESS: A patented metalcasting process that uses loose, free-flowing, unbonded sand to surround the fabricated expandable polystyrene pattern and gating system, which is then replaced by molten metal.

GATE: The portion of a gating system that connects the runner(s) with the mold cavity. Gates should be located in the cope.

GRAPHITE MOLDS: As applied to permanent mold casting, molds made of premium, high-density graphite rather than metal. Much faster mold production with excellent surface finish and dimensional accuracy can often compensate for some loss in mold life, and can remain cost effective.

GRAVITY-DIE CASTING: A term sometimes used (especially in Europe) to identify permanent mold casting, because the poured metal is under only atmospheric pressure.

GREEN COMPRESSION STRENGTH: The weight (in pounds per square inch) required to break a standard AFS sand specimen of tempered foundry sand.

GREEN SAND CORE: Core of molding sand produced by the pattern when ramming the mold.

GYRATORY RIDDLE: A mechanically operated screening device designed to screen, aerate, and remove particles of foreign material from foundry sand.

HAND SHANK: Crucibles are placed into shanks for pouring. A hand shank is designed to be held by one person.

HAZARDOUS WASTE: Any material that requires special handling during disposal so that it cannot affect soil or water adversely. Among the properties that characterize hazardous waste are ignitability, corrosivity, reactivity, and toxicity.

HEAT-CURED CORE: Core made of sand and binder systems that are hardened and cured by the application of heat.

HEAT DISPOSABLE PATTERNS: As applied to investment or lost wax casting processes, any pattern made of wax, certain types of plastic, or organic material that will burn out of an investment-type mold, leaving a cavity identical to the original pattern.

HORIZONTAL GATING SYSTEM: A gating system in which runners and gates lie in a horizontal plane.

HOT BOX CORE: Solid core made of sand grains coated with thermosetting plastic resin and an acid catalyst. A wet sand mixture is blown into a hot corebox, where the sand adjacent to the corebox walls is hardened in 10–20 seconds, allow-

ing the core to be removed. The center of the core continues to harden as heat transfers inward and the exothermic nature of the curing action occurs.

HOT-CHAMBER DIE CASTING MACHINE: A die casting machine in which the metal injection mechanism is submerged in the molten metal.

HOT (LIVE) RISER: Riser located between the mold cavity and the sprue. A riser in this position is filled with some of the last-poured (hottest) metal in the system. Properly sized and located hot risers function by accepting the shrinkage that otherwise would have taken place in the casting.

HOT MELT ADHESIVES: A newer adhesive in cartridge form that is melted and forced with pressure from a special gun. Its fast-setting characteristics produce core assemblies in shorter amounts of time.

HOT TEAR: Crack in a casting formed at elevated temperatures, usually by contraction stresses during solidification.

H-PROCESS: A patented metalcasting process that uses double-sided sand molds, booked together in a string and a gating system that allows each mold to fill only after its upstream neighbor has filled. All pouring is done at the first mold. Top gating from a *runnersphere* keeps gating to a minimum and increases yield.

INDUCTION FURNACE: A melting unit wherein the metal charge is melted electrically by induction.

INFORMATION PROCESSING: The collection, classification, storage, retrieval, dissemination, and so on of information (as compared with the processing of materials to produce consumer products.)

INGOT MOLD: Simple metal mold (usually coated) into which extra metal (or metal that has fallen below the desired pouring temperature) is emptied.

INOCULANT: Material added to a molten metal or alloy in small amounts to modify its structure and improve its physical and mechanical properties.

INTERNAL CHILL: Inserts (made of a metal compatible with that being cast) that are pushed into the side wall of a mold so that the largest mass of the chill (which extends into the mold cavity) will promote solidification. *See also* CHILL; EXTERNAL CHILL.

INVESTMENT CASTING: A process of producing metal castings in molds made of a refractory slurry known as *investment*.

INVESTMENT FLASK CASTING: A process in which a wax pattern cluster is surrounded with a *flask*, which is then filled with a refractory slurry. After the investment has set, the pattern is removed with heat, leaving a cavity (identical to the pattern) to receive metal. Although the process is somewhat faster than shell casting is, it is more expensive and more restrictive with respect to the size of castings that can be produced.

INVESTMENT SHELL CASTING: A process in which a mold is formed by dipping a wax pattern cluster into a refractory slurry, stuccoing the wet surface with refractory grain and drying. The dipping, stuccoing, and drying steps are repeated until an appropriate shell thickness has been achieved. The pattern is removed with heat, leaving a cavity (identical to the pattern) to receive metal.

INVESTMENT TIME: As applied to shell core or shell mold making, the amount of time the resin-coated sand remains in the hot corebox or hot pattern plate. The hotter the box or pattern plate, the shorter the investment time required to produce a shell core or mold of appropriate wall thickness.

IRON PICK-UP: Molten aluminum tends to dissolve iron, with the iron becoming a contaminant in the aluminum. All iron and steel tools and equipment (pyrometers, plungers, skimmers, ingot molds, and the like), should be covered with an appropriate coating of some kind to prevent contamination of the aluminum, which is known as iron pick-up.

JOLT-SQUEEZE MACHINE: A foundry machine that, using compressed air, packs the sand in the drag by jolting and, later, the sand in both the cope and the drag by squeezing.

LATCH BAR: As applied to tongs, a bar pivotally attached to one tong arm that can be used to lock both tong arms together after the crucible is properly positioned in the tongs. This safety feature eliminates the possibility of the crucible dropping out of the tongs.

LIQUID SHRINKAGE: The contraction that occurs as molten metal cools from the temperature at which it was poured to the temperature at which it starts to solidify.

LOAD: To plug the spaces between abrasive particles of a grinding wheel with foreign material, rending the wheel ineffective.

LOOSE PATTERN: A pattern not mounted to a plate. When molded, such patterns must be pulled with some kind of a temporary handle, such as a draw screw. Loose patterns are used infrequently in industry except for producing prototypes and for short runs of very large castings.

LOOSE PIECES: A general term for specific parts of a pattern or corebox that are used to promote efficiency, reduce tooling costs, or permit pattern or core removal.

LOST FOAM PROCESS: A process that produces castings from molded polystyrene patterns. The patterns are coated with a refractory wash, dried, and then surrounded by compacted, unbonded sand. Metal poured into the mold vaporizes and replaces the foam pattern.

LOST WAX PROCESS: A metalcasting process for one-of-a-kind castings in which the mold is produced by investing a pattern made of wax or some other heat-disposable material in a refractory slurry. After the refractory material has set, heat is used to eliminate the pattern (leaving a cavity identical to the pattern) and metal is poured (or forced) into the cavity.

LOW-PRESSURE CASTING: A casting method in which a minimal amount of pressure (usually 5–15 pounds per square inch) is used to fill a die.

MANIPULATOR: Robotlike machine requiring an operator who uses the master arm of the manipulator in manual mode or programming that allows the machine to function in semiautomatic or automatic modes.

MANUFACTURING: The production of goods (generally with machinery) in a systematic manner that often involves a division of labor.

MATCHPLATE: A plate with one or more patterns and, possibly, some portions of the gating system, that is cast as an integral unit.

METAL MATRIX COMPOSITE: Engineered material consisting of fibers of graphite, silicon carbide, or oxides added to a metal matrix. Such materials provide higher tensile strengths and improved elevated temperature properties with reduced weight.

MISRUN: A casting that is not fully formed.

MOLD HARDNESS: A quick test (commonly made on the molding floor) that indicates how firmly foundry sand has been packed in forming a mold. This hardness is determined by how far the ½-inch diameter penetrator (of an instrument about the size of a watch) indents the surface of the sand.

MULLER: A machine designed to mix foundry sand.

MULTIPLE CAVITY DIE: A die possessing two or more identical cavities; these dies can produce several identical castings per shot.

NATURAL FOUNDRY SAND: Foundry sand mixed by nature. It is taken from deposits where an appropriate amount of clay (15–22 percent) is uniformly mixed with the sand. This sand can be used for making molds after proper tempering with water.

NEAR-NET SHAPE: A term used to express the current goal of most metalcasters—to produce castings that match the drawing as closely as possible and that can be put into service with the least amount of additional processing.

NECK: The passageway through which molten metal in a riser feeds the casting.

NET SHAPE: A term used to express the ultimate goal of metalcasting—to produce castings that match the drawing exactly and can be put into service with no additional processing.

NO-BAKE CORE: A core made of sand and binder systems that are hardened and cured by chemical bonding.

NOMOGRAPHS: Marked-off graphs on which a straight edge can be used to connect two known values to find a third, unknown, value.

OIL-SAND CORE: Heat-cured core made of sand, oil, and cereals. The moist sand mix is rammed into a corebox, stripped from the box, and baked in an oven.

OIL-TEMPERED (WATERLESS) FOUNDRY SAND: A synthetic foundry sand containing a formulated material that, when combined with oil, serves as a sand-bonding agent.

OLIVINE FOUNDRY SAND: A water-base synthetic foundry sand, the basic ingredient of which is olivine sand. Olivine sand has lower thermal expansion and higher resistance to thermal shock than does silica sand, but it is more expensive.

OPEN RISER: A riser that extends to the top surface of the cope.

OSHA: Occupational Safety and Health Administration, established by a federal act that went into effect in 1971. OSHA's purpose is to provide safe and

healthful working conditions for all workers, thus preserving our human resources.

PAPER/GLUE JOINT: An ordinary glue joint—usually involving two surfaces (rather than edges)—into which a piece of paper is placed before closing and clamping the joint. Such a joint enables the joint to be split after the desired shaping has been done.

PARTING LINE: The line on a casting (or pattern) that corresponds to the separation between the cope and drag portions of a sand mold.

PATTERN CARRIER: As applied to the V-process, a hollow-chamber, 5-sided box, attached to a vacuum line. The pattern (with many appropriately placed tiny vacuum holes), when sealed in place as the top (sixth) side, enables thin, heated plastic to be vacuum-formed to the pattern.

PERMANENT MOLD CASTING: The production of castings by pouring metal (under atmospheric pressure only) into long-life molds.

PERMEABILITY: A measured property of foundry sand; the time (in seconds) it takes for 2000 cubic centimeters of air (at a pressure of 10 grams per square centimeter) to pass through a standard AFS sand specimen before it is stripped from the specimen tube.

PHOS-COPPER SHOT: Material in shot form produced from a 15 percent phosphorous copper alloy. Added to copper base alloy melts after skimming and just before pouring, phos-copper shot will deoxidize the melt, control the hydrogen content, increase fluidity, reduce porosity, and produce cleaner castings with better surface finish and detail.

PICKOUT: A loose piece that, if part of a pattern, remains in the mold until after the pattern is pulled and is then picked out of the mold and reattached to the pattern; or a loose piece that, if part of a core box, is removed with the core, picked out of the core, and reset in the box.

PINHOLE: Small holes on the cope surface or throughout a casting, commonly caused by gassy metal.

PLAIN CRUCIBLE TONGS: Hot crucibles must be handled with crucible tongs. Plain crucible tongs are designed to be used by one person who is handling small crucibles.

PLAIN PLATE: A plate (plywood or metal) to which one or more loose patterns have been permanently attached.

PLASMA: A gas-like collection of charged particles containing approximately equal numbers of protons and electrons, which differs from a gas in that it is a good electrical conductor and it is affected by a magnetic field.

POURING BASIN: A basin placed or "cut" at the top of the sprue. The basin should be designed so that it holds metal poured into it until the metal flows over a dam before flowing down the sprue. This must be accomplished without preventing a flow of metal sufficient to keep the sprue full.

PROGRESSIVE SOLIDIFICATION: The dendritic and columnar growth of solidification from the skin of the casting toward its center.

PYROMETER: Instrument used for measuring temperatures higher than those commonly measured with a mercury thermometer. Temperatures are determined by the increase in electrical resistance of a metal, by the generation of an electrical current by a thermocouple, or by the increase in intensity of light radiated by an incandescent body.

RAT TAIL: A small irregular line or series of lines in the casting resulting from buckling of sand in the mold wall.

RISER: That portion of a gating system designed to accept the liquid and solidification shrinkage of a casting that has heavy sections. Many castings made in a school foundry, especially those that have uniform wall thickness, do not require risers.

ROBOT: Machine that can be programmed to perform functions ordinarily done by human beings.

RUNNER: That portion of a gating system that delivers metal from the sprue base to the gates. Located in the drag, runners should be stepped down, or tapered, so that all gates receive about the same amount of metal.

RUNNER EXTENSION (SUMP): That portion of the runner that extends beyond the last gate. A runner 6 inches long, or a sump that will hold an equal volume of metal, traps the first metal poured (which is inevitably damaged) and prevents it from entering the cavity and becoming part of the casting.

RUNNERSPHERE: As applied to the "H" process, the horizontal runner that is formed above the castings as a string of "H" process molds are poured.

RUNOUT: Undesirable loss of molten metal through the parting line of a flask during pouring.

SAND HOLE: Cavity of irregular shape and size whose inner surface plainly shows the imprint of granular material occurring most commonly on drag surfaces of the casting.

SAND RAMMER: A specialized piece of sand-testing equipment that is used with a specimen tube to produce an AFS sand specimen. A weighed amount of tempered foundry sand is added to the specimen tube, and the hand crank of the sand rammer is turned, causing a weight to be dropped three times from a certain height, thus ramming the sand to form a specimen that should be 2 inches (52 millimeters) in height.

SEMI-PERMANENT MOLD CASTING: A method of permanent mold casting in which destructible cores made of materials such as sand or plaster are used.

SHAKEOUT: The operation of removing castings from a sand mold.

SHELL CORE: Hollow core made of sand grains coated with thermosetting plastic resin. A hot corebox is filled with the dry sand mixture and the box is emptied when the sand nearest the corebox walls forms a shell as a result of the heat from the corebox that moves toward the center of the core.

SHELL MOLDING: A process of producing metal castings in dry, thin-walled sand molds formed by bringing thermosetting resin-coated sand into contact with hot metal patterns.

SHOCK HEATING: As applied to investment casting, placing the mold in the presence of high heat (1500F, 815C) for a very short time so that the *exterior* of a wax pattern will melt and run out of the mold leaving space for the remaining wax to expand (without cracking the mold) as it melts under low heat (250F, 122C) and drains out of the cavity.

SHOT SLEEVE: As applied to a cold chamber die casting machine, the cylinder into which molten metal is poured and then forced into the die by the plunger.

SHRINK: To contract, become smaller. Most metals shrink as they cool from a liquid to a solid to room-temperature. In metalcasting, shrinkage must be anticipated and allowed for by making the patterns used to make molds larger by an appropriate amount than the desired casting.

SHRINKAGE: The decrease in volume that occurs before, during, and after the solidification of molten metal.

SHRINKAGE DEPRESSION DEFECT (SHRINK): A cavity, usually on the cope surface above heavier sections of a casting, that results from insufficient feed of metal.

SHRINK RULE (SHRINKAGE RULE): Shrink rules appear (at first glance) to be ordinary rules but are 1⁄16–3⁄8 inch per foot longer. A rule stamped "Shrinks 1⁄4 inch to 12 inches" is 12 1⁄4 inches long. The extra 1⁄4 inch is equally distributed throughout the entire length of the rule.

SIDE RISER: The most commonly used type of riser; located to the side of (rather than over) the casting, close to the anticipated area of shrinkage.

SILICA FOUNDRY SAND: The most commonly used water-base synthetic foundry sand, the basic ingredient of which is silica sand.

SINGLE CAVITY DIE: A die casting die which, in addition to the gating system, contains only one cavity.

SLAG: A nonmetallic material floating on the surface of molten metal consisting of impurities that have united with the flux.

SLAG COAGULANT: A material placed on the top of molten metal (copper-base alloys, gray iron, etc.) just before it is poured that facilitates complete slag removal.

SLAG HOLE: As applied to cupola furnaces, the hole at the rear of the cupola (opposite the tap hole) from which slag runs when the level of molten metal (and slag) in the well of the cupola rises to the height of the slag hole.

SLAG TRAP: As applied to the "H" process, the portion of the runnersphere above the well and weir in which floating slag is trapped.

SODIUM SILICATE/CO_2 CORE: Vapor-cured core made of sand and a sodium silicate binder (containing breakdown agents). The moist sand mixture is rammed into a corebox and gassed with carbon dioxide (CO_2) before stripping.

SOLIDIFICATION SHRINKAGE: The contraction that takes place as a metal or alloy solidifies; most such materials solidify through a range of temperatures rather than at a specific temperature.

SPALL: The surface deterioration of concrete resulting from heat—the surface looks as if it had been chipped with a hammer.

SPANGLES: The mottled appearance, more shiny (spangles) in some places than in others, of a metal such as galvanized iron. Aluminum with excessive iron pick-up will have a similar appearance.

SPRUE BASE: That portion of a gating system that receives metal as it exits from the sprue. It can be round or square. Its cross-sectional area should be 5 times that of the bottom of the sprue. It should be twice as deep as the depth of the runner(s) that it feeds.

SPRUE CUTTER: Tapered brass tube used to cut sprues. It is important that a sprue cutter be tapered. For most school foundry molds, the lower end should be about ½ inch in diameter (⅝ inch at the most).

STATIC HEAD: The distance of the pouring basin or cup above the mold cavity or lost foam pattern.

STATIC POUR OPERATION: As applied to permanent mold casting, a situation in which the mold remains stationary during pouring and solidification of the metal.

STRIP TIME: The time a core must remain in a corebox so that it will retain its shape when removed.

SURFACE FINISH: As applied to metal castings, the relative smoothness of the surface of a casting as it comes from the mold—after standard cleaning processes, but before machining.

SYNTHETIC FOUNDRY SAND: Foundry sand mixed to specifications. Clean, clay-free sand is mixed with carefully apportioned amounts of clay (and often, other materials such as cereal, wood flour, sea coal, etc.).

TAPERED SPRUE: A sprue can be circular, rectangular, or square in cross-section, but it should be tapered so the cross-sectional area of the bottom is one third to one half that of the top.

TEMPERATURE PEAK: The highest temperature a melt reaches before starting to cool. Even after a crucible furnace is turned off, the temperature of *aluminum* usually continues to increase. It is important that the *peak* temperature be reached before the degassing of aluminum is carried out.

TEMPERING: The addition of water to a clay-bonded sand mixture in order to develop plasticity; this makes the sand mixture moldable.

THIN-WALL CASTING: An effort by metalcasters who work with iron (in response to competitors' use of lighter-weight materials in the production of engine blocks) to achieve weight reduction of iron blocks by reducing the wall thickness of the casting.

THIRD WORLD COUNTRIES: A group of nations, especially in Asia and Africa, that are underdeveloped in comparison with the rest of the nations of the world.

TILT POUR OPERATION: As applied to permanent mold casting, a situation in which the mold is tipped at a controlled rate from a horizontal to a vertical position after the pour cups have been filled with molten metal.

TOP RISER: A less commonly used type of riser located above the anticipated area of shrinkage on the casting. Removal can be very expensive.

TUBE FILLER ACCESSORY: A specialized piece of equipment used in making a compactibility test. Locators position a specimen tube directly under a funnel-like object which has a 1/4-inch mesh screen at its top. Tempered foundry sand is passed through the riddle and funnel until the tube is filled to overflowing. The excess said is then struck off, and the sand rammer used to ram the sand and determine its compactibility.

TUYERE: Openings in the wind box through which the air blast enters the cupola.

UNIT DIE: A rather special die-casting die that enables various portions of a die to be assembled in a common holder. Tooling and production economies are often achieved with unit dies, in that several parts for an assembly or for different customers can be cast at the same time.

UNPRESSURIZED GATING SYSTEM: A gating system designed to slow down the velocity of the metal as it travels through the gating system so that it enters the mold quietly. This is achieved by making the cross-sectional area of the gates and runner(s) larger than the cross-sectional area of the choke.

V-PROCESS: A patented metalcasting process in which the mold is formed of dry, loose, free-flowing, unbonded sand that is caused to hold its shape by means of sealing special vacuum chamber flasks with thin plastic and pulling a vacuum on the flask before it is stripped from the pattern.

VAPOR-CURED CORE: Core made of sand and binder systems that are hardened and cured with a gas of some kind.

VENTS: Small openings in a mold (usually the cope) to facilitate the escape of air and gases from the mold when it is poured.

VIBRATOR: A device that utilizes compressed air or an electric current to set up vibratory motion. When used with a matchplate, the vibrator reduces friction between the sand and the matchplate, facilitating its easy removal from the sand.

WASH: Casting defect resulting from erosion of sand by flowing metal. Also a term for coating materials applied to molds, cores, etc.

WATER-TEMPERED FOUNDRY SAND: Any material or synthetic foundry sand (containing clay) that is conditioned for use by adding the correct amount of water to it.

WEIR: As applied to the "H" process, a specific part of the runnersphere that serves as a dam in controlling the direction and velocity of the molten metal as it starts to fill the next mold in the string.

WELL: A pouring basin.

WHISKER VENTS: Shallow depressions (made with a wire) on the parting surface of a mold (radiating from the cavity) to facilitate the escape of air and gases from the mold when it is poured.

WHISTLER (FLOWOFF): Specialized vent cut from the runner extension or sump through the cope to facilitate the escape of air and gases from the mold when it is poured.

WIND BOX: The chamber that surrounds the cupola at its melting zone. It

accepts large volumes of air from a blower and forces the air through a number of small openings (tuyeres) into the cupola.

WROUGHT METALS: Metals formed to their shapes (sheet, plate, structural shapes, etc.) by pressure rollers as opposed to casting.

YIELD: The percentage of good, degated castings produced in relation to the total amount of metal melted and poured. For example, if 50 pounds of good, degated castings result from pouring 100 pounds of metal, the yield is 50 percent.

Test Your Knowledge Answer Key

CHAPTER 1

1. charcoal
2. Do not try to lift loads beyond your capacity.
3. To drive off any moisture that might be present.
4. opened
5. melters' and pourers' face shield; leggings; gloves (mittens)
6. Hand squeeze test to see if sand will retain imprints of fingers, supports itself when held by one end, and breaks with sharp corners.
7. flask
8. sand cores
9. chaplets
10. crucible
11. aluminum
12. shakeout
13. laborer, e; executive, c; patternmaker, g; sand technician, f; technical sales representative, h; quality control engineer, a; metallurgical engineer, i; safety technician, d; molder, b

CHAPTER 2

1. foundry tooling
2. 2
3. shrinkage; machining
4. acclimatized
5. T
6. casting
7. polyester putty
8. F
9. hard plasters
10. speed up
11. T
12. electroless
13. T
14. loose pieces
15. loose
16. T
17. ¾ inch
18. T
19. T
20. vents

CHAPTER 3

1. dry sand
2. weaker
3. before
4. 400–425°
5. cross-sectional
6. heat
7. sodium silicate/CO_2
8. water
9. hot box
10. hollow; solid
11. chemical
12. T
13. continuous mixer
14. shell core
15. hot melt
16. core wash
17. water; alcohol

CHAPTER 4

1. T
2. T
3. pouring basin
4. tapered
5. F
6. F
7. drag; cope
8. 4; 4
9. 5
10. 2
11. T
12. tapered
13. F
14. 6
15. sump
16. directional
17. F
18. ½
19. bulb
20. dome
21. neck
22. 1

CHAPTER 5

1. moist
2. silica; water
3. F
4. shovel
5. compactibility
6. solidification
7. T
8. T
9. drag; cope; drag
10. 8
11. ¾
12. molding; down
13. facing
14. T
15. drag
16. moistening; rapping; pulling
17. bottom board
18. T
19. T

CHAPTER 6

1. cupola
2. induction
3. T
4. T
5. slightly oxidizing
6. 10; 30
7. clay
8. F
9. plunger
10. one
11. shanks
12. T
13. wrought
14. F
15. F
16. peaks
17. aluminum; copper-base
18. T
19. T
20. rubber gloves

CHAPTER 7

1. zero (to eliminate)
2. lower
3. detective
4. blow
5. cold shut
6. pinholes (porosity); sand holes
7. misrun
8. shrinkage

CHAPTER 8

1. F
2. a reducing oxyacetylene flame
3. die casting
4. shell molding
5. T
6. investment
7. investment
8. 9
9. clean; slurry
10. T
11. F
12. F
13. simpler
14. higher
15. lost foam
16. F
17. vacuum form plastic film over the pattern
18. F
19. F
20. sand
21. pattern carrier
22. off
23. H
24. yield
25. below

CHAPTER 9

1. information
2. sand; permanent
3. graphite
4. iron
5. T
6. manipulators; robots
7. die casting
8. computer-aided drafting
9. aluminum
10. permanent mold; die casting; investment casting; lost foam; V-process (any three)
11. permanent mold; die casting; investment casting (any two)
12. F
13. F
14. OSHA

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